# OPTICAL STUDIES WITH CHLORO-NITROSO CAMPHANE DERIVATIVES

with an additional paper on

## THE PHOTOELECTRIC POLARIMETRY AND LOW-TEMPERATURE ABSORPTION SPECTROSCOPY OF (-)-β-CARYOPHYLLENE NITROSITE

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# HISTORICAL AND THEORETICAL INTRODUCTION

## I - Classical

The rotation of the plane of polarised light by quartz, observed but misunderstood by Arago (1811) (1, 2), was investigated fully by Biot (1812-1838) (3). To him we owe the discovery, not only of rotatory polarisation in crystals and in liquid media, but also of rotatory dispersion - the change of rotation with wavelength.

$$\alpha = {}^{k}/_{\lambda^2} \qquad \text{(Biot)} \ldots\ldots\ldots (1)$$

It was Fresnel (1822) (4), however, who provided a kinetic interpretation of optical rotatory power. He showed that a plane polarised ray, on entering an active medium, is resolved into two circular components, one right- and one left-handed. These traverse the medium with different velocities, a phase difference is set up, and on leaving the medium they recombine to give a polarised ray whose plane of polarisation is inclined to that of the original. His mathematical proof, elegant in its simplicity, involved the compounding of wave equations for transverse vibrations, e.g.

$$\eta_1 = a \sin \frac{2\pi}{\tau}\left(t - \frac{x}{v_1}\right) \quad , \quad \xi_1 = a \cos \frac{2\pi}{\tau}\left(t - \frac{x}{v_1}\right) \text{ ; right-handed.}$$

$$\eta_2 = a \sin \frac{2\pi}{\tau}\left(t - \frac{x}{v_2}\right) \quad , \quad \xi_2 = -a \cos \frac{2\pi}{\tau}\left(t - \frac{x}{v_2}\right) \text{ ; left-handed}$$

From these is derived the equation

$$\eta/\xi = -\cot \frac{\pi x}{\tau}\left(\frac{1}{v_2} - \frac{1}{v_1}\right) \quad ; \quad \left(\tau = \frac{\lambda}{v}\right).$$

whence it can be deduced that, in a distance of 1cm., the plane of polarisation rotates through an angle $\alpha$ given by

$$\alpha = \pi/\lambda (n_l - n_r) \qquad \ldots\ldots\ldots (2)$$

where $n_l$, $n_r$ are the refractive indices for the left- and right-handed circularly polarised components respectively. The relationship between $\alpha$ and $\lambda$ is important. In general, rotation increases with decreasing wavelength. Biot's Inverse Square Law (Eqn. 1) was early recognised to be inadequate (5), and later empirical modifications by Stefan (6) and Boltzmann (7) proved to be of little use.

The first theoretical treatment of optical activity was given by Drude (8), who based his treatment on Maxwell's electromagnetic theory of light. Drude's "dissymmetrically isotropic medium" was provided by ions, the paths of which are "short helices twisted in the same direction and whose axes are directed at random in space". In such a medium, the rotation, $\alpha$, is given by

$$\alpha = \sum \frac{k}{\lambda^2 - \lambda_o^2} \qquad \ldots\ldots\ldots\ldots (3)$$

where $\lambda_o$ is the wavelength of a characteristic vibration. The equation predicts accurately the values of $\alpha$ in the region of transparency. However, it also presents the rotation as increasing asymptotically to infinity as $\lambda^2 \to \lambda_o^2$, followed by a reversal of sign on crossing the wavelength

of maximum absorption (Fig. I). A parallelism with sodium vapour, the refractive index of which changes with wavelength as predicted by Equation 3, is not to be expected in compounds whose circular refractions are controlled by absorption bands of considerable width.

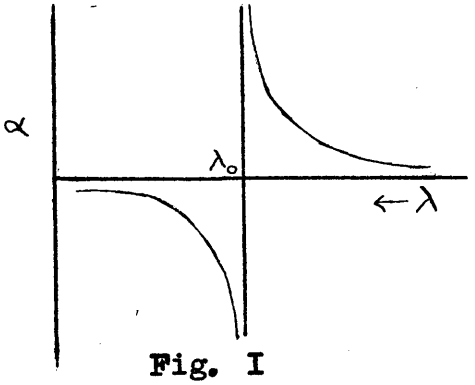



Fig. I

Drude's treatment received much criticism. It was finally dismissed by Kuhn(9) who pointed out that Drude had neglected a factor which would reduce the rotatory power of his model to zero. The work of Cotton(10) on coloured active tartrates, where the absorption band is situated in the readily accessible visible region of the spectrum, showed that $\alpha$ does not tend to infinity as $\lambda^2 \longrightarrow \lambda_o^2$ . In the case of potassium chromium tartrate the rotation rises to a maximum on the long-wave side of the band, falls to zero in the middle and reaches a minimum on the short-wave side. The rotation is said to be anomalous in the region of absorption.

This work of Cotton on active tartrates was undertaken as a direct consequence of his pertinent deduction that, by analogy with the linear dichroism shown by tourmaline,(11), the circular components in an active medium might suffer unequal absorption. His postulate was fully justified by the investigation of a solution of potassium chromium tartrate, where the right and left components were absorbed to the extent of 92.3 and 91.2 per cent respectively. This unequal absorption of the two components is known as circular dichroism and is represented by $(\varepsilon_l - \varepsilon_r)$ where $\varepsilon_l$ and $\varepsilon_r$ are the molecular extinction coefficients for left- and right-handed circularly polarised light respectively. Circular dichroism reaches a maximum at the wavelength of maximum absorption (only true when the absorption process is unique) and falls off rapidly as the absorption tends to zero. There is thus a similarity between (i) the change of ordinary refraction (n) with absorption ($\varepsilon$) and (ii) circular double refraction (optical rotation) with circular dichroism $(\varepsilon_l - \varepsilon_r)$. This is illustrated in Figure II.

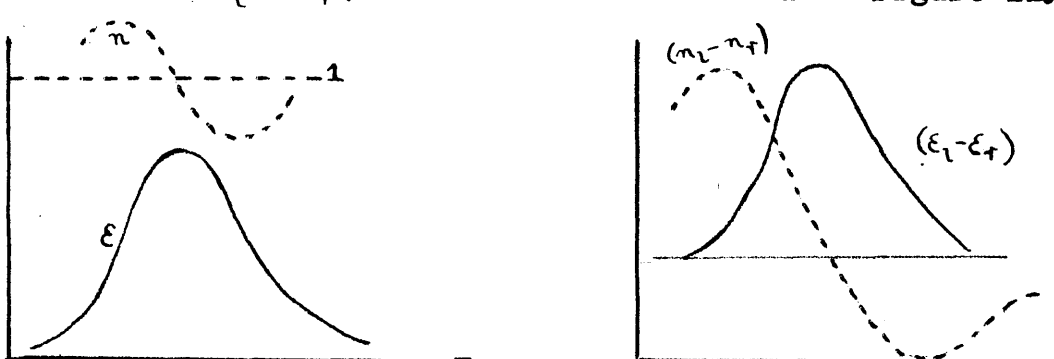



Fig II.

Although circular dichroism cannot occur except in the region of absorption, there is no exact quantitative relationship between them. The passage of a plane polarised ray through a circularly dichroic medium results not only in the rotation of the plane of polarisation but in the production of an emergent elliptically polarised ray. The ellipticity ($\phi$) is expressed as

$$\tan\phi = \frac{a_r - a_l}{a_r + a_l} \qquad \text{.....(4)}$$

where $a_r$ and $a_l$ are the amplitudes of the right and left rays respectively. Provided $\phi$ is small, $\tan\phi \simeq \phi$ , and since $a_{r,l} = \frac{a_o}{2} \cdot e^{\frac{-\varepsilon_{r,l} t}{2}}$

$$\phi \text{ (in radians)} = \frac{c.l.(\varepsilon_l - \varepsilon_r)}{4 \log_{10} e} \qquad \text{.....(5)}$$

These combined phenomena - circular dichroism and anomalous rotatory dispersion in the region of absorption - are known as the Cotton effect. A proportionality between the ratio of circular dichroism to absorption, and frequency, i.e. $\varepsilon_l - \varepsilon_r / \varepsilon \propto \nu$ , can be deduced from Natanson's equation for circular dichroism(12) and the Ketteler-Helmholtz equation for the absorption of unpolarised light. This relationship proved of great consequence in later theoretical work (p.12 ). A rule connecting the sign of rotation with circular dichroism was formulated by Natanson and

Bruhat(13): "on the long wavelength side of an optically active absorption band, the sign of the elliptical vibration is the same as the sign of rotation, while on the short wavelength side the ellipse is of opposite sign to the rotation". Thus, a Cotton effect showing positive rotation on the long-wave side of $\lambda_{max.}$ is positive, and vice versa.

The optical activity of organic compounds was attributed by Le Bel and van't Hoff to the presence of an asymmetric carbon atom. However, it was soon recognised that this was but a particular example of Pasteur's generalisation that over-all molecular dissymetry was the cause of optical activity. This focussing of attention on the asymmetry of the individual molecule was a natural consequence of the inadequacy of Fresnel's rigid-helix theory when applied to active solutions with molecules orientated at random.

The work of almost a century had 'tracked down' optical activity to the symmetry conditions of molecules, but had left unanswered the fundamental problem of what interaction between polarised electromagnetic radiation and a non-centrosymmetric molecule causes the plane of polarisation to be rotated.

The opening years of the present century saw great

advances in a more accurate conception of atomic and molecular structure. The ideas accrued from this have provided the mathematical chemist with a new tool, thereby enabling him to solve in principle the problem of optical activity.

## II - Modern

Two satisfactory theories have been developed, one framed in the classical oscillator theory of dispersion and the other in wave-mechanical terms. The latter, though yielding rather unwieldy formulae, is based on a more accurate description of molecular processes. Both theories give essentially the same results, several of which are of prime importance to the practising photochemist and which will be discussed in Section III.

The application of classical dispersion theory to the problem of optical activity was proposed independently, and almost simultaneously, by Born(14) and Oseen(15). These authors regarded a molecule as a system of discrete units which are polarised under the action of the electric vector of a polarised light wave. The fields of force associated with these displaced units then interact with each other so that the resultant

polarisation is due to the combined influence of the radiating electric field and of the fields created by all the other units of the molecule. This idea of interacting resonators is known as 'coupling'. In his original theory, Born showed that at least four, non-planar, isotropic electrons (these were considered to be the vibrating units) were necessary for the production of optical activity. In this treatment, uncoupled electrons contributed nothing to the rotatory power, a view which does not agree with the more modern treatments of rotation and absorption. The purely wave-mechanical calculations of McMurry(16, 17), on the strength of the long-wave band characteristic of the ketonic group, showed that (i) the transition is a forbidden one, deriving its intensity mainly from the perturbation of the permitted and very intense band at about 1900A. and (ii) the electrons involved are the non-bonding electrons on the hetero-oxygen atom. This has been expressed as the change $2p_y \rightarrow 2p_z$ by Mulliken(18), or as an N→A transition(19) which has no electric moment of transition in any direction. The appreciable anisotropy factor associated with such groups must therefore be derived from the associated magnetic transition moment. In the words of Lowry, Simpson and Allsop(20,21):

"The act of rotation of the plane of polarisation takes place when the electron (unshared) is raised to its excited state, the orbital of which is located in the double bond".

Kuhn(22) applied the coupled vibrator theory to a rather simplified molecular model embodying two anisotropic, linear oscillators (x, y) separated by a distance, d. With the introduction of a coupling force, a vibration of one resonator must perturb the other. Mathematical analysis shows that with coupling two modes of vibration are still possible, these being denoted by $\xi_1$ (of frequency $\nu_1$) and $\xi_2$ (of frequency $\nu_2$) respectively. The displacements of the particles in both vibrations are:

$$x(\xi_1) = a\cos 2\pi\nu_1 t, \quad y(\xi_1) = -\frac{1}{4\pi^2 m_y}\cdot\frac{k_{xy}\, a\cos 2\pi\nu_1 t}{\nu_2^2-\nu_1^2}$$

$$x(\xi_2) = -\frac{k_{xy}\, b\cos 2\pi\nu_2 t}{4\pi^2 m_x(\nu_1^2-\nu_2^2)}, \quad y(\xi_2) = b\cos 2\pi\nu_2 t \qquad \ldots\ldots(6)$$

Kuhn showed that the energy transferred to one vibration is different for a right- and left-handed circularly polarised beam, resulting in a difference in the indices of refraction for the two types of polarisation and thus in optical activity. Moreover, when the incident light frequency corresponds to one of the natural frequencies, the difference in the energy transferred means a difference in the intensity of absorption of a

right- and left-handed ray. Such an effect (circular dichroism) was observed by Cotton in 1896(10). Having established the activity of such oscillators, Kuhn then proceeded to calculate the magnitude of the rotation associated with them. In the case of very weak coupling, the rotation ($\phi$) was given by

$$\phi = \text{const.} \left\{ \frac{k_{12}\, d.\nu^2}{\nu_1^2 - \nu_2^2} \left[ \frac{1}{\nu_1^2 - \nu^2} - \frac{1}{\nu_2^2 - \nu^2} \right] \right\} \quad \ldots\ldots (7)$$

where $k_{12}$ = constant associated with coupling force.

$d$ = distance of separation,

$\nu_1, \nu_2$ = characteristic frequencies of system.

$\nu$ = frequency of incident light.

Born's criticism(23, 24) of this treatment, namely the unreality of the model, is to the modern chemist too strict and unimaginative. Kuhn, of course, realised that active diatomics of this type could not exist since one, two or three atoms have always a plane of symmetry (the plane of the two or three nuclei). The most obvious defects of the treatment are the over-emphasis of a coupling distance 'd', associated with molecular dimensions, and the reduction of group polarisability (anisotropy) to a straight line. These, however, are outweighed by the success attending the application of Equation 7 to experimental results. The fundamental contribution made by Kuhn was the

identification of the coupled oscillator frequencies with those of natural absorption bands. Certainly Drude and other workers made use of $\lambda_o$, the frequency of maximum absorption, but to them it was a limiting factor rather than an integral part of the mechanism of rotation. To Kuhn "a molecule is optically active if the vibrating moment corresponding to a given absorption band has various components in the different parts of the molecule and at least two of these components are not parallel to each other". This corresponds very closely to the modern interpretation of absorption processes in terms of an electrical or magnetic moment of transition. In general, permitted transitions are those in which the new nodal plane (excited state) is at right angles to one vector of the incident radiation. Coupling can then take place between electric-electric or electric-magnetic moments (see p. 16). The activity of classically symmetrical groups, for example the ketonic group in camphor, was interpreted in terms of the inducing or vicinal function of neighbouring substituents.

To the photochemist, the most interesting result of Kuhn's theory is the connection between the intensity of a band and its contribution to optical rotation. The intensity of a band, given by its oscillator-

strength (f)(25, 26, 27) is

$$\int \varepsilon \, d\nu = \frac{N f \pi e^2}{mc}.$$

The contribution of this band to the ordinary refraction is

$$(n-1)\xi_1 = \frac{Ne^2}{2\pi m} \cdot \frac{f}{\nu_1^2 - \nu^2}.$$

The contribution to the circular dichroism is

$$(n_l - n_r)\xi_1 = \frac{Ne^2}{2\pi m} \cdot \frac{f_g}{\nu_1^2 - \nu^2} \cdot \frac{\nu}{\nu_1}$$

Thus

$$\frac{(n_l - n_r)\xi_1}{(n-1)\xi_1} = g$$

or

$$\frac{\varepsilon_l - \varepsilon_r}{\varepsilon} = g \text{ (a constant)} = \text{Anisotropy Factor..(8)}$$

This factor 'g' is the amount by which the contribution to the ordinary refraction has to be multiplied to get the contribution to the optical activity. It thus gives a measure of the activity of a band. It can be shown that only weak bands can have high anisotropy factors, a fact supported by experiment and capable of interpretation in terms of transition-moment theory (p.16). Moreover, the derivation of this relationship helps to dismiss as untenable the polarisability theories of Boys(28) and Kirkwood(29). As was pointed out by Lowry and Allsopp(30), the weak bands of molecules, having moderately large rotations (e.g. camphor ketone band), contribute in general very little to the

polarisability of the molecule. This can only be brought into conformity with theory if Kirkwood's anistropy ratio ($\delta$) were to change markedly with wavelength without altering the polarisability - which is unlikely. It is interesting to note once more that Kauzmann and his collaborators(31) suggest that, in polarisability theory, the optical activity of weak bands is associated with electric-magnetic moment coupling (p. 16 ).

What is perhaps the most correct treatment of rotatory power, based on more accurate descriptions of molecular processes, has been developed by Condon, Altar and Eyring(32). These authors used as their starting-point the results of the quantum-mechanical approach to optical activity presented in detail by Condon in 1937(33). In this are integrated Maxwell's Electro-magnetic Field Theory and the calculations of Rosenfeld(34) on the electric and magnetic moments induced in a molecule by a perturbing electromagnetic field. Condon's expression for [M], the molecular rotation, is

$$[M] = \frac{96\pi N}{hc} \cdot \frac{n^2+2}{3} \cdot \sum_{a_i} \rho_{a_i} \sum_{b_i} \frac{R_{b_i a_i} \nu^2}{\nu^2_{b_i a_i} - \nu^2} \qquad \ldots\ldots (9)$$

where

$Pa_i$ is the probability that the molecule lies in a particular electronic state with definite relative positions for the atoms, i.e. for a definite conformation of atoms.

$Rb_i a_i$ = rotatory strength of transition

= imaginary part of scalar product of matrix components

$$(a_i/p/b_i) \text{ and } (b_i/m/a_i)$$

where

p = induced electric moment

m = induced magnetic moment

$\nu_{ba}$ = frequency of transition a→b

Here again, attention has been focussed on the connection between the act of rotation and the transition moment involved in going from state 'a' to state 'b'. Mathematically the problem has thus been solved. The application of Equation 9 to a model was carried out by Condon, Altar and Eyring, the basis of whose treatment was the recognition of a correlation between absorption and optical rotation. The interpretation of molecular spectra(35) in terms of one-electron transitions indicated that rotatory power might be treated by the same method. In general, these transitions are located in a particular chromophoric group (e.g. $\rangle C{=}O$; $N{=}O$; $-N_3$ etc.). The problem thus resolved itself into one of determining the initial and final electronic states of these one-electron transitions of the chromophore. The perturbation of these states by neighbouring groups (vicinal action)

leads to altered states, between which transitions are optically active provided the system has no centre of symmetry. The eigenfunctions of the two perturbed, non-degenerate states are

$$\psi_a = \psi_a^\circ + \Sigma c_a \psi$$
$$\psi_b = \psi_b^\circ + \Sigma c_b \psi \qquad \ldots\ldots\ldots (10)$$

where $\Sigma c\psi$ are perturbation terms, and $\psi_a^\circ$, $\psi_b^\circ$ are the unperturbed states (inactive) which are taken to be hydrogen-like and of the form, for example,

$$\psi_{2p_y} = \frac{1}{4\sqrt{2\pi}} \left(\frac{Z}{a_o}\right)^{5/2} \left(e^{\frac{-Zr}{2a_o}}\right) y.$$

Five types of perturbing forces (vicinal forces) were considered by these authors. These were:-

1) Dipole forces. This was successfully applied to phenyl methyl carbinol nitrite.

2) Ionic fields and charges.

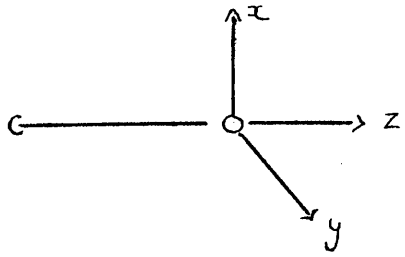
3) Perturbation of the surrounding atoms by overlapping of the electronic cloud of the chromophore.

4) 'Exchange' energies caused by the 'blurring' of electron individuality by the overlapping of electronic orbits.

5) van der Waals forces.

The one-electron theory offers a simple explanation of the activity associated with weak absorption bands. Thus, the carbonyl band is believed to be due to a

transition between a $2p_y$ and a $2p_z$ orbital with the development of a new nodal plane at right angles to the molecular axis ($n \rightarrow \pi^*$, N→A)(16, 19, 31, 36). This transition, which of necessity must be associated with




a large magnetic moment (there is no change in the electrical centre of gravity), can then couple with the perturbing small electric moment also associated with the band. This is, in the broadest sense, the explanation given by Kuhn's coupled-vibration theory. He did not specify that the vibrations were produced by the oscillations of electrons (misinterpreted by Lowry(37) ). To Kuhn, "the important factor was that the vibrating electric moment consisted of two components, at right angles to each other.....If we can obtain in any other way an absorption band with these properties, we will find it optically active in a similar manner"(22). The one-electron theory is really a refinement (both in the model and in the treatment) of Kuhn's theory. Both have indicated the

close correspondence between the mechanisms of absorption and rotation. A more precise definition of vicinal action is presented; the activity of weak bands has been interpreted in terms of transition moments; the anisotropy factor, first derived empirically by Natanson from Drude's theory, has now been given a deeper meaning in that it links band intensity with optical activity and, as will be shown, asymmetric photolysis.

The importance of optical activity in the future will depend largely on the recognition and application of the correlation between absorption and rotation processes. For example, a cursory examination of chromophores giving rise to large rotations (nitroso, carbonyl, xanthate, azido) brings to light one outstanding fact. These groups are characterised by low intensity bands, all of which could conceivably be attributed to forbidden transitions with large magnetic transition moments, for instance, the tentative assignment of the nitroso band as a quasi-forbidden, $n \rightarrow \pi^*$ (38) or singlet-triplet(27, 39, 40) transition.

These facts in themselves might provide the theoretical chemist with a new tool in helping him to assign correct transition types to certain absorption bands found in optically active molecules.

## III - Asymmetric Photolysis

Circular dichroism involves the unequal absorption of the two forms of circularly polarised light by an optically active medium. It thus follows that, in a racemic mixture, one enantiomorph will absorb one type of light more than the other. If, in addition, the material undergoes photolysis in that spectral region corresponding to the asymmetric unit, the rates of decomposition of the two isomers will be different if one type of circularly polarised light is used, and optical activity will arise. An equal amount of rotation of opposite sign is produced with the other type of circularly polarised light. This idea, though postulated about the beginning of the century, was not successfully realised until 1929 by Kuhn(41) and 1930 by Mitchell(42).

Several conditions must be satisfied before an asymmetric photolysis can be attempted. These are:-

1) The molecule must satisfy Pasteur's fundamental criterion of dissymmetry, viz. that it must have no centre of symmetry.
2) It must show a region of circular dichroism, i.e. an absorption band associated with the asymmetric centre.
3) The compound must be photo-sensitive within the region of circular

dichroism, so that the asymmetric unit is destroyed during photolysis. The active band in copper racemate is not photo-sensitive(42, 43), hence Cotton's unsuccessful decomposition with red light.

4) The quantum efficiency ($\gamma$) of the photochemical reaction should be approximately unity. Complicating secondary processes (chain and dark reactions) must be absent.

The fulfillment of conditions (1) to (4), though ensuring that asymmetric decomposition will take place, does not guarantee that the induced rotation will be large. The required optimum conditions for this can be deduced from Equation 11(44), which permits calculation of the induced rotation from data for one of the active isomers.

$$\alpha' = \alpha . g/2 . (1-\beta) . \log \frac{1}{1-\beta} \qquad \ldots\ldots\ldots (11)$$

where

$\alpha'$ = rotation developed from a solution of the dl mixture.

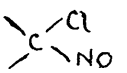
$\alpha$ = rotation for a solution of pure d or l compound (concentration equal to that of dl mixture at start).

$g$ = anisotropy factor.

$\beta$ = degree of decomposition ($\alpha'$ is a maximum when $\beta = 0.6$).

Accordingly, the greater the values of $\alpha$ and $g$, the larger the value of $\alpha'$. The greatest values of the anisotropy factor 'g' are obtained when the circular

dichroism and absorption are large and small respectively.

Kuhn and Braun(41) recorded the first successful asymmetric photolysis with ethyl α-bromopropionate which, after 50 per cent decomposition with ultraviolet light, developed a rotation of 0.05°. The dimethylamide of α-azido propionic acid yielded much better results(44). After 37 per cent decomposition with left-handed circularly polarised ultraviolet light, the isolated, unchanged dimethylamide showed a rotation of -1.04° in a 1dm. tube for mercury yellow light. The most numerous and interesting decompositions carri ed out from 1930 onwards are by Mitchell, who has concerned himself primarily with nitroso compounds which, if monomeric, show a readily determined Cotton effect in the red region of the spectrum. Of these, perhaps the most important are the invariably monomeric chloro-nitroso compounds of the type  prepared by the action of chlorine on the ketoxime. They possess several advantageous features, viz.:

1) They are generally solids.

2) In solution, their absorption bands are conveniently situated in the visible spectrum.

3) They decompose under the influence of light to give the oxime hydrochloride or chloro-nitro compound in the absence and presence of

oxygen respectively(45).

4) The quantum efficiency of the process is generally about unity(46).

Positive results have been obtained with:-

1) Humulene nitrosite(42).

2) β-chloro-β-nitroso-αδ-diphenyl butane(47).

3) β-chloro-β-nitroso-γγ-dimethyl butane(48).

The optical enantiomorphs of these were not available and consequently this work yielded only half of the required data. Active chloro-nitroso compounds were then synthesised by two methods:-

1) By direct resolution, e.g. (-)-γ-chloro-γ-nitroso-δ-phenyl valeric acid(49). A successful decomposition was carried out but the results were poor and did not warrant further investigation of this line of approach.

2) By making use of directional asymmetric synthesis, starting from an active ketone. The ketonic, active terpenes offered the most obvious starting-point and the optical properties of (-)-2-chloro-2-nitrosocamphane (B.1)(50), viz. $[\alpha]$ 6000 = + 964°; $[\alpha]$ 7100 = -946°; g = -0.15 at 7200A, appeared to make it eminently suitable for the work envisaged. Irradiation with red light, however, caused an extremely rapid mutarotation, thus marring its usefulness for asymmetric photolysis.

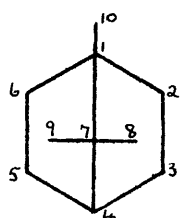
Although complicated by this photomutarotation, the optical properties of the parent compound justified the maintenance of the camphane skeleton in the continued search for chloro-nitroso terpenes suitable for asymmetric photolysis.

## SUBSTITUTED 2:2'-CHLORO-NITROSO CAMPHANES AND APOCAMPHANES

(-)-2-Chloro-2-nitrosocamphane (B.1)(50), prepared by the chlorination of d-camphoroxime in anhydrous ether, showed a Cotton effect, but $[\alpha]_{600}$ varied between +100° and +200° in different preparations. When prepared from the oxime hydrochloride the product had $[\alpha]_{600}$ +700° which, after chromatographic treatment, rose to +964°. The hydrochloride group appeared to be stereo-directing. A similar specificity has been observed in the conversion of β-benzilmonoxime into its more stable α-form(51). Irradiation of this chloro-nitroso camphane with red light from a 1000 c.p. Pointolite lamp caused an inversion of the curve of rotatory dispersion in about 60 minutes, with little change in absorption. The pyridine salt of (+)-2-chloro-2-nitrosocamphane-10-sulphonic acid(50) (B.4) did not mutarotate in this way under the same conditions, and therefore appeared suitable for asymmetric decomposition. The maximum value of the anisotropy factor ($g_o$) for the pyridine salt was approximately 26% smaller than the corresponding value for the parent camphane (B.1). This, with the overall smaller rotations of the salt and the potential photochemical instability of the pyridinium nucleus, outweighed the fact that it did not

mutarotate and made it unsuitable for asymmetric photolysis. The importance of B.4 was that it indicated a possible connection between the steric size of the substituent and isomerisation, and determined the approach to the problem of synthesising substituted chloro-nitroso camphanes suitable for asymmetric photolysis.

Position of the substituent

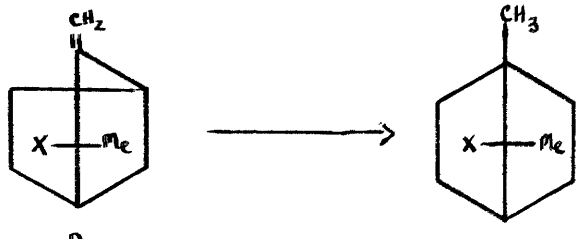



Since the final assessment of the effect of a substituent will be based on measurements of optical rotation, every effort should be made to ensure that substitution does not alter the configuration of the camphane nucleus. The observation of mutarotation as an inversion of the Cotton effect in the spectral range 500mμ -700mμ indicated that the nitroso group attached to $C_2$ was involved in group interchange. To be sterically effective, therefore, a substituent must be located at $C_3$, $C_{8,9}$, $C_1$ or $C_{10}$. The relative merits of each position are discussed separately.

Mono-substitution at $C_3$ introduces a new asymmetric centre, whose contribution to the total optical rotation

might complicate the rotatory dispersion in the visible spectrum, especially if the substituent were a chromophore (e.g. $NO_2$, Ph). Moreover camphors mono-substituted at $C_3$ can exist in two stereoisomeric forms, which are difficult to isolate in the pure state(52). Mono-alkylated camphors are high boiling oils(53) (difficult to purify) while the sterically efficient mono-halogenated and di-alkylated compounds do not form oximes(54, 55).

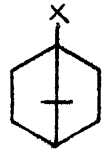
The experimental and stereochemical difficulties involved in mono-substitution at $C_8$ or $C_9$ were considered too great and no attempt was made to substitute at these points. A substituent located at $C_8$ (trans to $C_2$) would be too far removed from $C_2$ to allow any interaction to take place. Moreover, no synthesis is described which can differentiate between mono-substitution at $C_8$ or $C_9$. The preparation of such compounds is carried out in two ways: first, by direct substitution in an optically inactive camphor(56) with subsequent resolution of the product and, second, by rearrangement of substituted camphanes of the type A.




A.

The rearrangement of such compounds produces uncertainty in the stereochemical configurations of the products (e.g. the uncertainty in the configuration about $C_1$).

Many of the complications outlined above are eliminated by substitution at $C_1$ and $C_{10}$. Replacement of hydrogen in the $C_{10}$ methyl group (which does not involve the breaking of a bond on an asymmetric unit) can effect mo configurational changes(57). Substitution at $C_1$, involving the rupture of the $C_1$-$C_{10}$ bond, cannot change the configuration of $C_1$. This has been rigorously established by the work of Ingold, Bartlett(58), Barton(59) and Doering(60). A compound of the type B is inert to nucleophilic substitution by both $S_N1$ and $S_N2$ mechanisms.




B.

$S_N2$ reaction is impossible because the presence of the large gem-dimethyl group on the bridge does not allow the approach of the substituent on the side opposite that from which X recedes (a condition necessary for the formation of a stable transition complex with subsequent Walden inversion). $S_N1$ mechanism fails because the carbonium

ion (if formed) would be unable to take up its most stable planar configuration.

Nature of the substituent

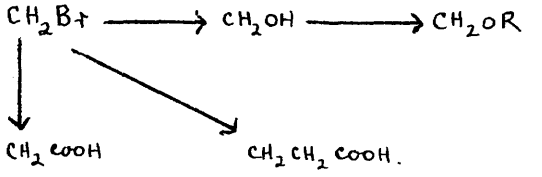
A physical prerequisite of the substituent is size, but to be of maximum use in the work envisaged, the substituent must also satisfy the following chemical requirements:-

(a) It must be inert both to chlorine and to the hydrochloric acid formed during the chlorination of the ketoxime. For this reason, such groups as C = C and $-NH_2$ are unsuitable.

(b) Irradiation with relatively intense light of wavelength 500 -700 should leave the substituent unchanged. In this, the effect of reactive photolysis products on the group should be considered. Esters, for example, although photochemically stable to light of this wavelength, would tend to be hydrolysed by hydrochloric acid formed by the decomposition of a chloro-nitroso compound.

(c) Light absorption by a chromophoric substituent should not extend into the near ultra-violet or visible spectrum.

(d) The substituent should be capable of easy replacement by others differing both in steric influence and in chemical characteristics, e.g.:

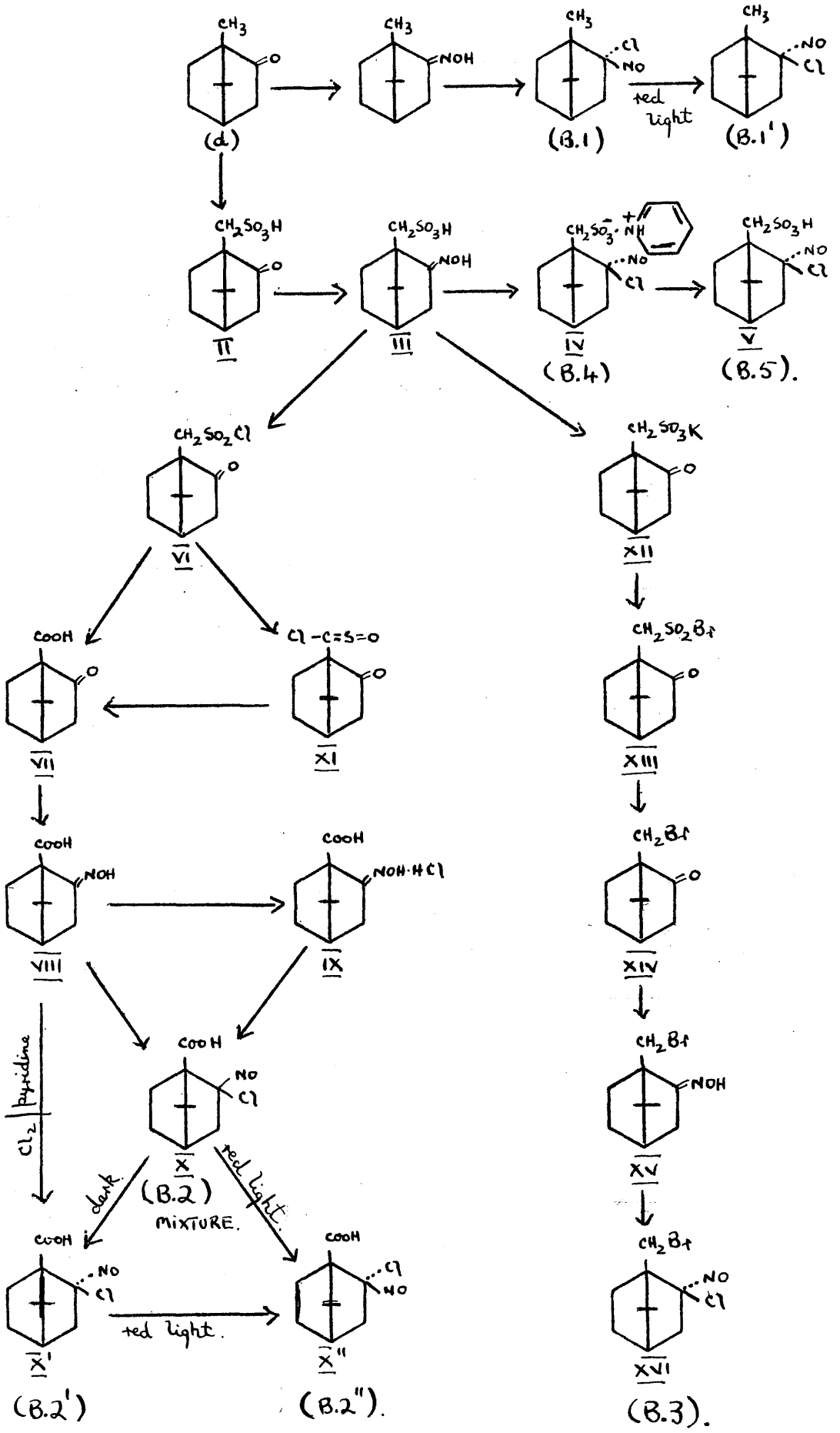


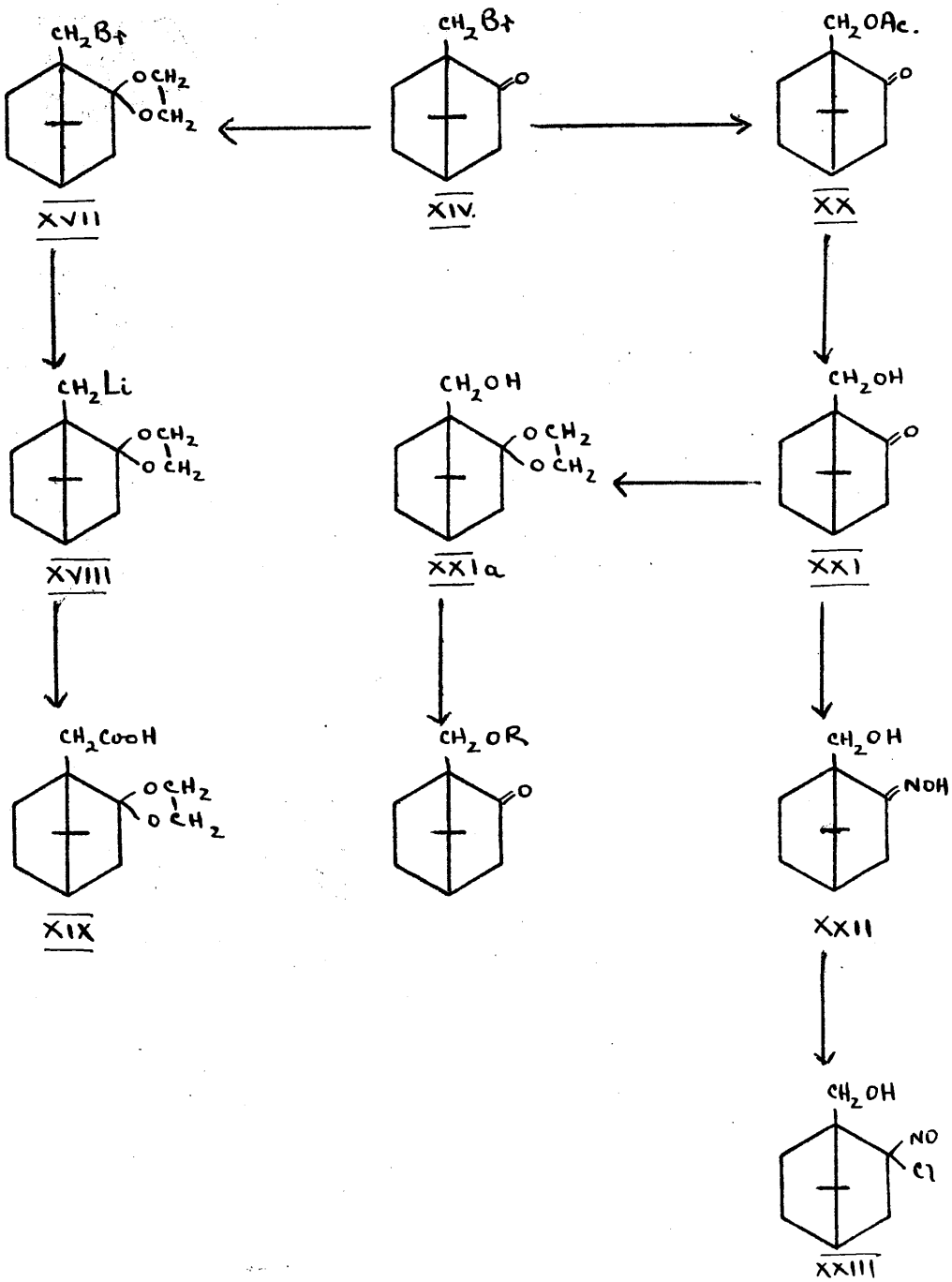

(e) The chloro-nitroso derivatives should

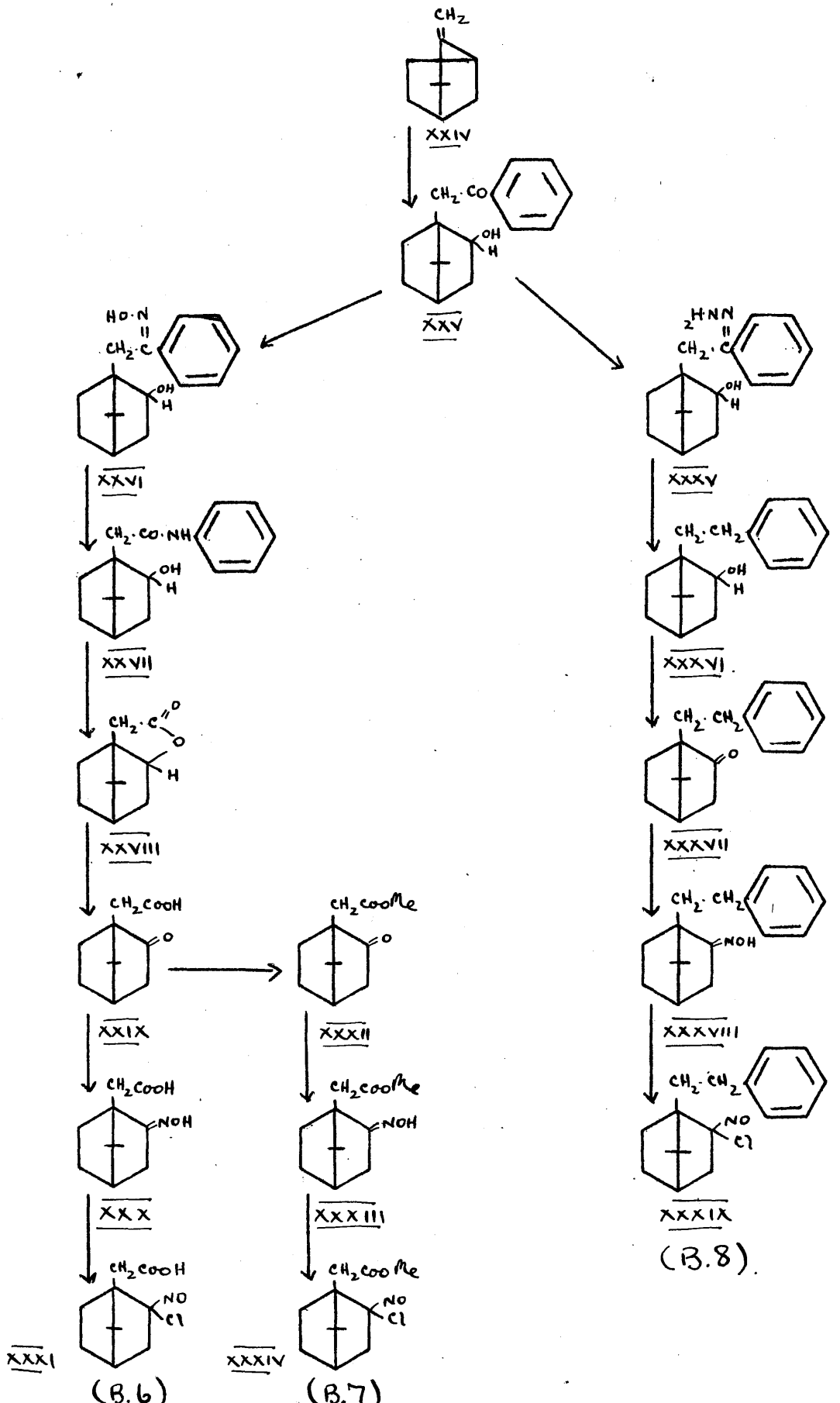
be crystalline solids. However it is very difficult to obtain the derivatives in this form as many of them are viscous oils.

The ultimate substituted camphors or apocamphors should, if possible, be derived from optically active starting materials. The advantages of a common starting material or intermediate are self-evident.

Integration of the facts presented in the last few pages led finally to a selection of compounds whose syntheses are outlined in the following flowsheets. It should be remembered, however, that several of the compounds were prepared at the dictates of the photochemical results, obtained during the course of this work.


(d)
(B.1)
red light
(B.1')
II
III
IV
(B.4)
V
(B.5).
VI
XII
VII
XI
XIII
VIII
IX
XIV
XV
pyridine
Cl2
dark
red light.
X
(B.2)
MIXTURE.
XVI
X'
X''
(B.2')
(B.2'').
(B.3).


CH2Br
CH2Br
CH2OAc.
XVII
XIV.
XX
CH2Li
CH2OH
CH2OH
XVIII
XXIa
XXI
CH2COOH
CH2OR
CH2OH
NOH
XIX
XXII
CH2OH
NO
Cl
XXIII


XXIV
XXV
XXVI
XXVII
XXVIII
XXIX
XXX
XXXI
(B.6)
XXXII
XXXIII
XXXIV
(B.7)
XXXV
XXXVI
XXXVII
XXXVIII
XXXIX
(B.8)

## THE OPTICAL BEHAVIOUR OF SUBSTITUTED CHLORO-NITROSO CAMPHANES AND APOCAMPHANES

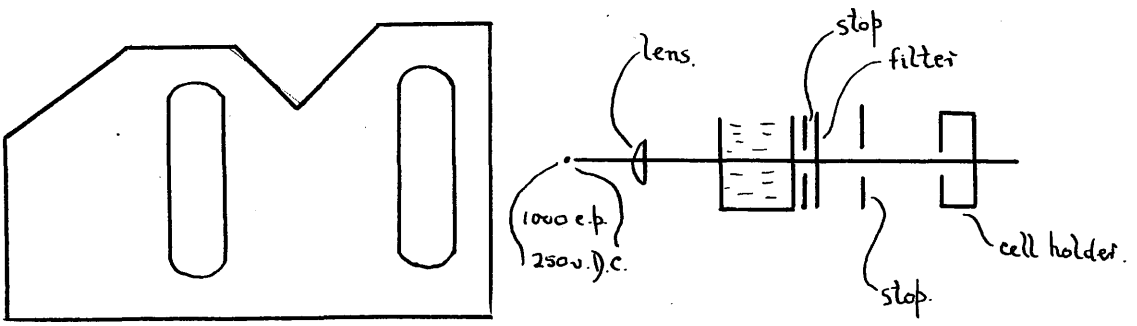
### I - Notes on Experimental Procedure

Rotation measurements were made visually with a spectropolarimeter constructed from a Hilger triple-field polarimeter (reading to 0.01°) and a Winkel-Zeiss monochromator. A 12-volt, battery-supplied projection lamp served as light source. A constant 'half-shadow' angle of about 5° was used in the determination of the rotatory dispersions of all the chloro-nitroso compounds investigated. A $\lambda/4$ plate, introduced behind the polarising system, allowed ellipticity measurements to be taken with the spectropolarimeter(61). Rotation of the $\lambda/4$ plate was controlled by an arrangement exactly similar to the analyser fine-adjustment. Both regulating screws were fitted with graduated drums, one division of which corresponded to 0.012°. Readings of ellipticity were taken in a cell 0.25dm. in length, in which the strain-free end pieces were held to the main tube by optical contact.

Absorption spectra were determined with a Unicam SP. 500 photoelectric spectrophotometer. The slit-width at the wavelength of maximum absorption of the chloro-nitroso camphanes rarely exceeded 0.04mm. The spectral

distribution of this instrument is 43mμ per millimeter of slit-width at 650mμ. The wavelength scale is calibrated in 5mμ per division from 600-1000mμ, so that the slits used fell within the limits imposed by the scale calibration. The wavelength of maximum absorption was always determined first.

The chloro-nitroso compounds were irradiated under almost identical conditions. Light from a shielded 1000 candle-power Pointolite lamp traversed a large, short-focus condensing lens, a water-jacket (carrying a stop, of diameter 4.1cm.), a red filter and a second stop (2cm. diameter); it then fell on the reaction cell (9.95mm. thickness), which was housed in a blackened holder with a circular aperture of diameter 1.8cm. This is illustrated diagrammatically below. A special cell holder was constructed which could be accommodated in the cell compartment of the spectrophotometer (Diagram I). The slits of the Winkel-




I

Actual Size.

Zeiss monochromator were kept constant while the change of rotation (at one wavelength) with irradiation was determined. Unless otherwise stated, all solutions were made up in absolute ethanol which had been freed from dissolved oxygen as far as possible by heating under reflux for one half-hour in an atmosphere of dry nitrogen. A flow of nitrogen was maintained until the solvent had reached room temperature. In the text, such solutions will be designated 'oxygen-free'. No attempt was made to control the temperature during irradiation as the temperature coefficients of most photochemical reactions are small. In this work, the temperature variation never exceeded +4°C.

## II - 2-Chloro-2-nitroso-apocamphane-1-carboxylic acid (X.B.2).

The approach to the syntheses of non-mutarotating chloro-nitroso camphanes must, of necessity, be determined by the results derived from a detailed investigation of the influence of environmental changes on the photochemical stability of the chloro-nitroso group. The theoretical and practical difficulties involved in substitution have been outlined in the preceding section. The β-keto acid (VII), 2-keto-apocamphane-1-carboxylic acid (ketopinic acid), was chosen as the first member of a series of substituted camphanes (or apocamphanes) varying in size and chemical characteristics. The replacement

of methyl by carboxyl on $C_1$ involved principally a change in the nature of the substituent rather than in its size. Moreover, it was readily accessible and satisfied most of the criteria set out in pages 26-7 .

The solubility of the acid-oxime (VIII) in ether was low and restricted the scale of preparation of the chloro-nitroso derivative. Chlorination of VIII in anhydrous ether, according to the method of Mitchell and Dawson (47), gave a crystalline solid of relatively high melting point. Purification was effected first by passage through a column of silica-gel (benzene as solvent and eluent) and then by crystallisation from a mixture of benzene and petroleum ether. Analysis confirmed that this compound was 2-chloro-2-nitroso-apocamphane-1-carboxylic acid (B.2). The optical properties of the blue compound were disappointing. The values of specific rotation (Table I) and molecular extinction coefficients (Table II) were low and high respectively. These are illustrated in Graph I. The absorption curve showed the 'step-out' on the short wave side of max, characteristic of nearly all monomeric chloro-nitroso compounds. The complicated Cotton effect, which cut the axis of zero rotation twice, was the first observed with molecules of this type and indicated a marked weakening of the directing powers of the asymmetric

carbon atom ($C_1$) giving rise to a mixture of both possible diastereoisomers. Evidence that this was indeed an equilibrium mixture was afforded by the 'dark reaction' shown by the blue material prepared from the oxime in ether. Examination of an ethanolic solution of B.2 which had been kept in total darkness for about one month (not necessarily a minimum time) showed a simplification of the curve of rotatory dispersion (Graph 1, Table 1). The curve was poorly developed and the 'indentation' between 580 and 610 mμ indicated the presence of opposing contributions to the optical rotation. However, it was essentially the rotatory dispersion of (+)-2-chloro-2-nitroso-apocamphane-1-carboxylic acid (B.2').

The formation of B.2' by 'dark reaction' was time-consuming and it was thought that the stereospecific action of the oxime hydrochloride in producing pure (-)-2-chloro-2-nitrosocamphane (B.1, page 22 ) might offer a rapid means of displacing the equilibrium discussed above. Passage of dry hydrogen chloride into an ethereal solution of VIII precipitated an almost equal mixture of the oxime hydrochloride and free oxime. When this procedure was carried out in acetone, the oxime hydrochloride (IX) was obtained in good yield and was characterised by analysis. Chlorination of IX in

TABLE I

Rotatory Dispersion of 2-chloro-2-nitroso-apocamphane-1-carboxylic acid

A : from oxime in ether : c = 0.0190g./10ml. Not 'oxygen-free'

B : from oxime hydrochloride : c = 0.0191g./10ml. Not 'oxygen-free' } l=1dm.

C : dark reaction. Time in total darkness, 29 days 20 hours : c = 0.0191g./10ml. 'oxygen-free'

| λ(mμ.) | $\alpha_A$ | $\alpha_B$ | $\alpha_C$ | $[\alpha]_A$ | $[\alpha]_B$ | $[\alpha]_C$ |
|---|---|---|---|---|---|---|
| 510 | +0.08 | +0.29 | -0.05 | + 42 | +152 | - 26 |
| 520 | +0.09 | -- | -0.06 | + 47 | -- | - 31 |
| 530 | +0.10 | +0.30 | -0.10 | + 53 | +157 | - 52 |
| 540 | +0.07 | -- | -0.12 | + 37 | -- | - 63 |
| 550 | +0.05 | +0.29 | -0.16 | + 26 | +152 | - 84 |
| 560 | -- | +0.27 | -0.17 | -- | +141 | - 89 |
| 570 | +0.01 | +0.21 | -0.22 | + 5 | +110 | -115 |
| 580 | -- | -- | -0.20 | -- | -- | -105 |
| 590 | +0.01 | +0.17 | -0.16 | + 5 | + 89 | - 84 |
| 600 | +0.00 | -- | -0.15 | 0 | -- | - 79 |
| 610 | -0.09 | +0.05 | -0.24 | - 47 | + 26 | -126 |
| 620 | -0.21 | -0.15 | -0.27 | -111 | - 79 | -141 |
| 630 | -0.22 | -0.22 | -0.14 | -116 | -115 | - 73 |
| 640 | -0.04 | -0.07 | +0.26 | - 21 | - 37 | +136 |
| 650 | +0.21 | +0.15 | +0.58 | +111 | + 79 | +304 |
| 660 | +0.28 | +0.25 | +0.55 | +147 | +131 | +288 |
| 670 | +0.21 | +0.16 | +0.40 | +111 | + 84 | +210 |
| 680 | +0.11 | +0.08 | +0.25 | + 58 | + 42 | +131 |
| 690 | +0.05 | +0.05 | +0.12 | + 26 | + 26 | + 63 |
| 700 | +0.03 | -- | +0.06 | + 16 | -- | + 31 |

TABLE II

Absorption Spectrum of 2-chloro-2-nitroso-apocamphane-1-carboxylic acid from the oxime in ether

Concentration, c = 0.0456g./5ml. : 'oxygen-free' : t = 1cm.

Mol. Wt. = 231.68 : M = 0.03936 : Slit at maximum=0.04mm.

| λ(mμ.) | $\log \frac{I_o}{I}$ | ε | λ(mμ.) | $\log \frac{I_o}{I}$ | ε. |
|---|---|---|---|---|---|
| 510 | 0.042 | 1.1 | 610 | 0.5875 | 14.9 |
| 514 | 0.052 | 1.3 | 615 | 0.633 | 16.1 |
| 520 | 0.063 | 1.6 | 620 | 0.703 | 17.9 |
| 524 | 0.072 | 1.8 | 625 | 0.77 | 19.6 |
| 530 | 0.090 | 2.3 | 630 | 0.825 | $20.9_6$ |
| 534 | 0.101 | 2.6 | 635 | 0.865 | $21.9_7$ |
| 540 | 0.125 | 3.2 | 640 | 0.875 | 22.2 |
| 544 | 0.1375 | 3.5 | 645 | 0.842 | 21.4 |
| 548 | 0.152 | 3.9 | 650 | 0.785 | 19.9 |
| 550 | 0.160 | 4.1 | 655 | 0.715 | 18.2 |
| 554 | 0.175 | 4.5 | 660 | 0.628 | $15.9_6$ |
| 558 | 0.192 | 4.9 | 665 | 0.519 | 13.2 |
| 560 | 0.209 | 5.3 | 670 | 0.4125 | 10.5 |
| 564 | 0.2325 | 5.9 | 675 | 0.3245 | 8.2 |
| 568 | 0.260 | 6.6 | 680 | 0.264 | 6.7 |
| 570 | 0.2745 | $6.9_7$ | 685 | 0.210 | 5.3 |
| 574 | 0.314 | $7.9_8$ | 690 | 0.1675 | 4.3 |
| 578 | 0.354 | $8.9_9$ | 695 | 0.1355 | 3.4 |
| 580 | 0.369 | 9.4 | 700 | 0.108 | 2.7 |
| 584 | 0.404 | 10.3 | 705 | 0.090 | 2.3 |
| 588 | 0.434 | 11.0 | 710 | 0.075 | 1.9 |
| 590 | 0.450 | 11.4 | 715 | 0.062 | 1.6 |
| 594 | 0.470 | 11.9 | 720 | 0.0515 | 1.3 |
| 598 | 0.498 | 12.7 | 725 | 0.042 | 1.1 |
| 600 | 0.513 | 13.0 | 730 | 0.035 | 0.9 |
| 605 | 0.55 | $13.9_7$ | | | |

# Graph I

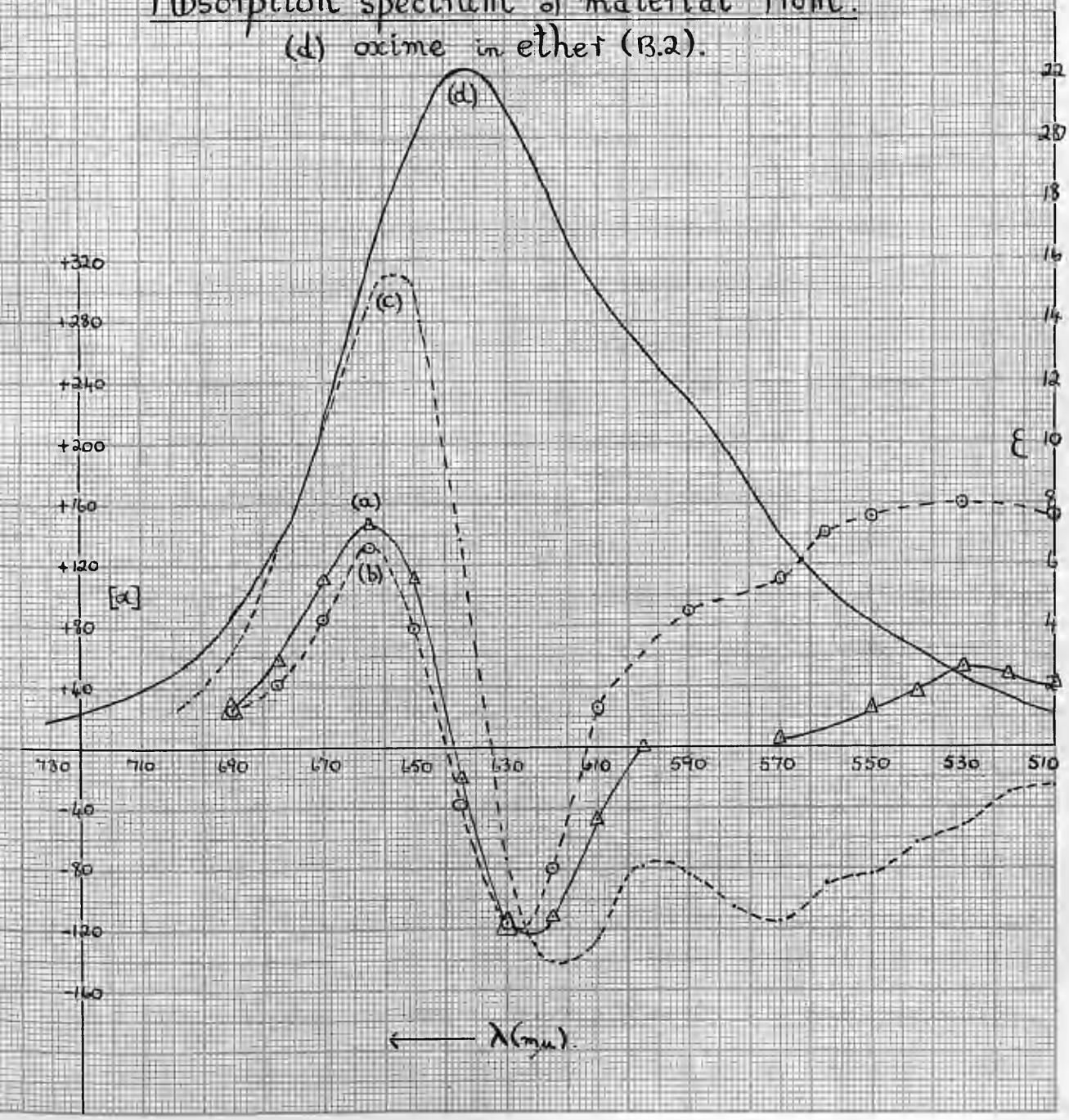
## 2-Chloro-2-nitroso-apocamphane-1-carboxylic acid.

### Rotatory dispersion of material from

(a) oxime in ether. (B.2).
(b) oxime hydrochloride in ether (B.2).
(c) from (a) after 29 days 20 hours in dark (B.2').

### Absorption spectrum of material from.

(d) oxime in ether (B.2).



ether gave a highly crystalline blue compound, a solution of which in ethanol showed once more a double crossing of the axis of zero rotation (Table I, Graph I). The equilibrium had not been displaced to any great extent, but a stereo-selective formation of the (-) isomer was evident from the greater development of rotation in the range 500-610mμ.

The optical properties of the blue acid made it unsuitable for asymmetric photolysis, but the effect of the carboxyl group on the photochemical stability of the chloro-nitroso group on $C_2$ had still to be determined. That the substituent had exerted some influence at this site was evident from the displacement of λ max. for B.1 and B.2 from 660mμ. to 640mμ. This represented a separation of the ground and excited levels. Irradiation with red light soon disclosed a fairly rapid mutarotation. The change in rotation with time of irradiation was followed at three wavelengths corresponding to the maxima in the curve of rotatory dispersion together with the change in $\log I_o/I$ at λ = 530 and 660mμ (Table III, Graph II). The solution used was too concentrated to permit accurate determination of the complete absorption curve after irradiation. Rotation values, corrected for photolysis, are tabulated for λ = 660mμ. The variation of $\log I_o/I$ at 530mμ. was too

TABLE III

Irradiation of 2-chloro-2-nitroso-apocamphane-1-carboxylic acid from the oxime in ether

Concentration, c = 0.0949g./5ml. : 'oxygen-free'.

l = 0.0995dm. : t = 0.995cm.

[α]'= specific rotation corrected for photolysis.

Rotation-Absorption at 530mμ

Slits:
Entrance = 1.1 : Exit = 1.1

| Mins. | α | $\log I_o/I$ |
|---|---|---|
| 0 | +0.10 | 0.195 |
| 15 | +0.11 | 0.1955 |
| 55 | +0.21 | 0.1925 |
| 115 | +0.33 | 0.191 |
| 175 | +0.42 | 0.192 |
| 235 | +0.51 | 0.191 |
| 325 | +0.57 | 0.1975 |
| No change overnight | | |
| 445 | +0.56 | 0.1855 |

Rotation-Absorption at 630mμ.

Slits:
Entrance = 2.1 : Exit = 1.9

| Mins. | α | $\log I_o/I$. |
|---|---|---|
| 0 | -0.25 | |
| 15 | -0.26 | |
| 55 | -0.31 | |
| 115 | -0.36 | |
| 175 | -0.42 | |
| 235 | -0.46 | |
| 325 | -0.50 | |
| No change overnight | | |
| 445 | -0.52 | |

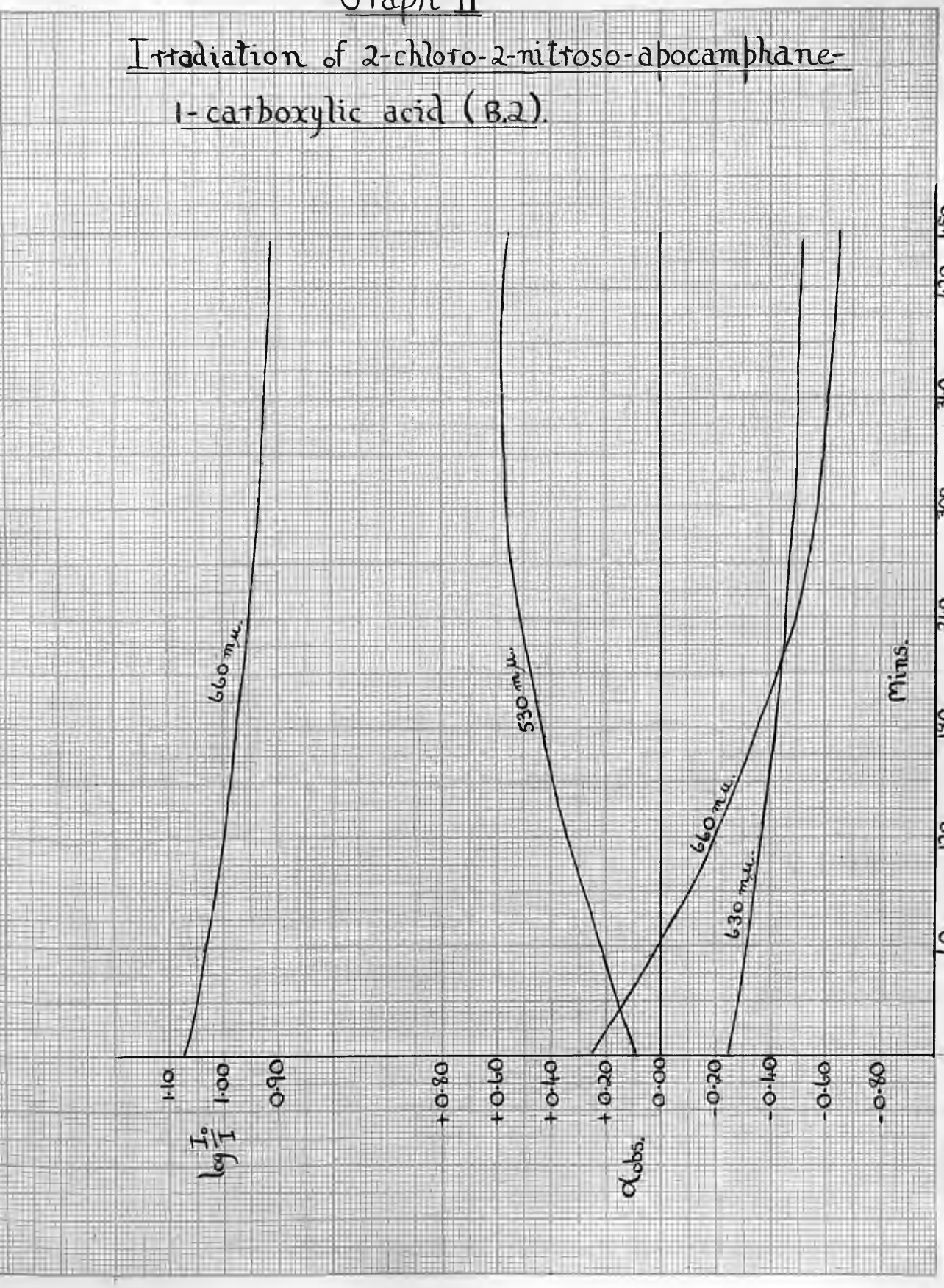
Rotation-Absorption at 660mμ.

Slits:
Entrance = 2.1 : Exit = 1.9

| Mins. | α | [α]' | $\log I_o/I$. |
|---|---|---|---|
| 0 | +0.26 | +138 | 1.075 |
| 15 | +0.24 | +130 | 1.05 |
| 55 | +0.04 | + 22 | 1.0375 |
| 115 | -0.19 | -108 | 1.00 |
| 175 | -0.34 | -198 | 0.975 |
| 235 | -0.49 | -294 | 0.95 |
| 325 | -0.59 | -363 | 0.925 |
| No change overnight | | | |
| 445 | -0.65 | -407 | 0.910 |

# Graph II

## Irradiation of 2-chloro-2-nitroso-apocamphane-1-carboxylic acid (B.2).



uneven to justify the presentation of corrected rotations, while $\log I_o/I$ at 630mμ. was too large to be measured on the spectrophotometer. A curve of rotatory dispersion, constructed from the observed rotations developed after 325 minutes of irradiation, is illustrated in Graph III (Table IV). The choice of time was determined by the 'flattening-out' of the curves of rotation and absorption against time.

The mutarotation took place without appreciable photolysis. The gradual development of rotation at 530 and 630mμ, with the change in sign of rotation at 660mμ (after 60 minutes ca.), was consistent with a greater rate of photoisomerisation for one of the diastereoisomers, namely the change of the (+) into the (-) form. The effect was markedly different from that shown by B.1. The rotatory dispersion curves for the mutarotated products were of the opposite sign; the values of [α] for B.1' were almost half of B.1. In this case, increases in rotation of 460% (at $\lambda$ = 530mμ) were observed (an effect which would be even greater if corrections for photolysis were applied). The rotatory dispersion curve of B.2" (Graph III) was much more symmetrically developed, indicating a large preponderance of one isomer. It should be noted that (a) the Cotton effect of B.2" was structurally similar to that for the

TABLE IV

Rotary Dispersion of (-)-2-chloro-2-nitroso-apo-camphane-1-carboxylic acid (B.2") after 325 minutes' irradiation of the blue material prepared from the oxime in ether

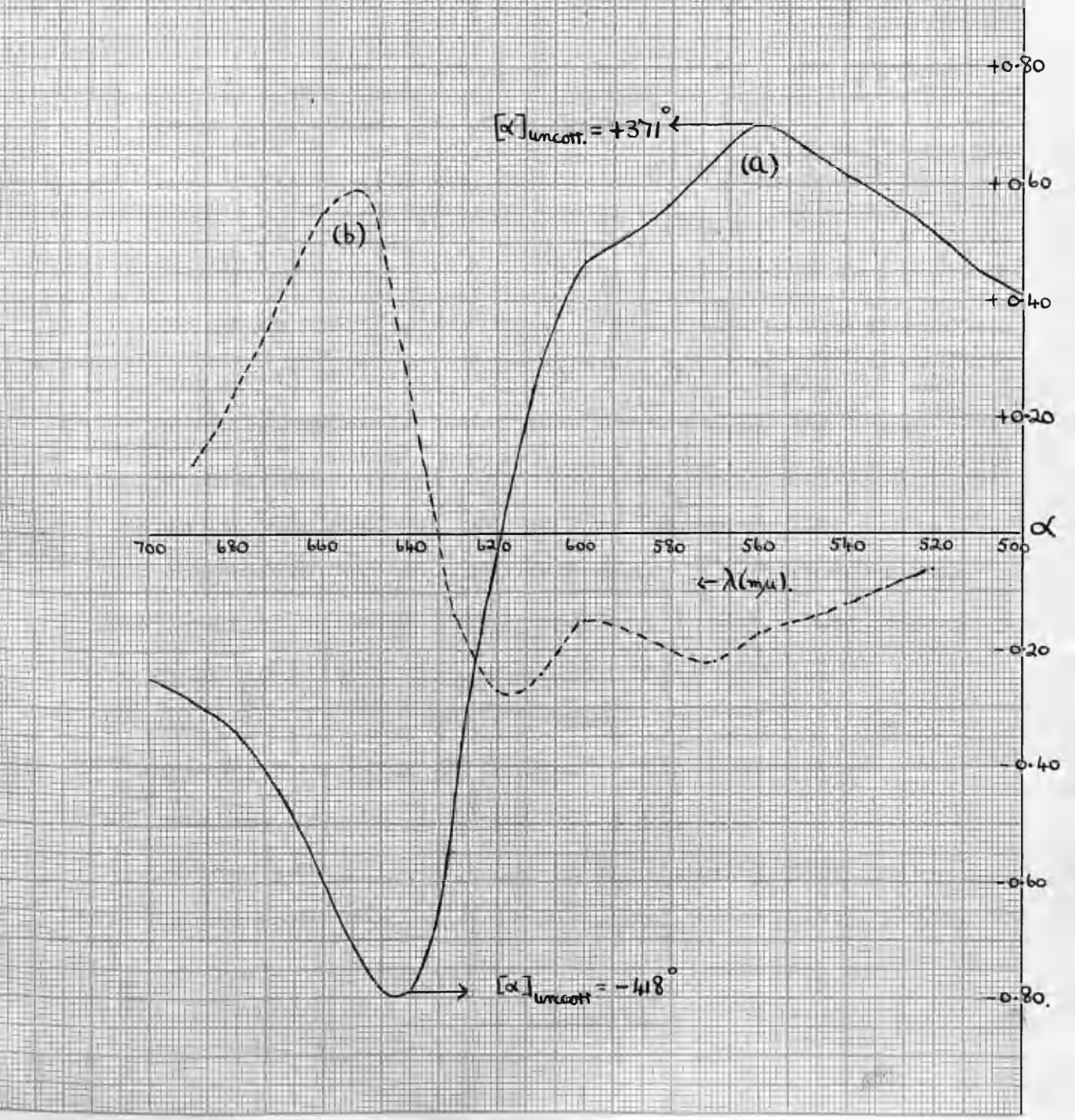
l = 0.0995dm.

| λ(mμ.) | α obs. |
|---|---|
| 500 | +0.41 |
| 510 | +0.45 |
| 520 | +0.53 |
| 530 | +0.57 |
| 540 | +0.61 |
| 550 | +0.66 |
| 560 | +0.70 |
| 570 | +0.64 |
| 580 | +0.57 |
| 590 | +0.51 |
| 600 | +0.47 |
| 610 | +0.30 |
| 620 | -0.04 |
| 630 | -0.50 |
| 640 | -0.79 |
| 650 | -0.75 |
| 660 | -0.60 |
| 670 | -0.44 |
| 680 | -0.34 |
| 690 | -0.29 |
| 700 | -0.25 |

# Graph III

(a) Rotatory Dispersion of (-)-2-chloro-2-nitroso-apocamphane-1-carboxylic acid after 325 mins. irradiation of B.2.

(b) Dark reaction of B.2 (see also Graph Ic).



pyridine salt of (+)-2-chloro-2-nitrosocamphane-10-sulphonic acid but of opposite sign and that (b) a comparison of ($\lambda$, $[\alpha] \simeq 0$) for B.2" and the 'dark reaction' product (Graph I) showed a displacement of about 10 mμ to shorter wavelengths. A similar displacement, but in the opposite sense, had been observed with B.1 and B.1' and proved of great consequence in later work.

Both the size and chemical nature of the carboxyl group have proved ineffective in hindering the photomutarotation of B.2. This functional group, however, did offer the possibility of substituent enlargement by, say, ester or salt formation, and it was hoped that by so doing, evidence for steric hindrance of the change would be obtained. By analogy with B.4, the preparation of the pyridine salt of B.2 was next attempted. The chlorination of the pure acid-oxime (VIII) in anhydrous pyridine, at about -18°C, resulted in the instantaneous formation of a deep-blue solid, easily soluble in ether and benzene. Analysis confirmed that it was a chloro-nitroso derivative of the free acid. The curve of rotatory dispersion (Graph IV, Table Va) further substantiated that it was isomeric with B.2 or B.2'. Furthermore, the shape of the curve indicated that this material, prepared from the oxime in pyridine, was essentially the (+) form identical with that from the

'dark reaction', i.e. B.2'. The indentation at 580-610mμ. and the wavelength of zero rotation were almost coincident. The identity of the 'dark reaction' and pyridine products was established by irradiation of the latter with red light. The results for this are given in Tables Va,b,c (Graphs IV, V, VI). The curve of rotatory dispersion constructed from the rotation values after 300 minutes (21% decomposition, Graph IV), was identical in shape with that obtained by irradiation of the mixture of isomers (B.2) and showed a displacement of 10-15mμ. to shorter wavelengths. The larger rotations for the (+) form permitted the use of a solution suitable for both polarimetric and spectrophotometric work. The spectrum obtained after this time (re-scaled to the original height) showed a corresponding displacement. The amount of shift, about 5mμ, lay well within the resolving power of the spectrophotometer at these wavelengths (page 29.). This remarkable band-shift was first observed by Hope (private communication) with (+)-2-chloro-2-nitrosopinane. These were but two isolated examples with molecules bearing little or no stereochemical relationship. The use of band-shifts as a diagnostic test for photoisomerisation was not realised until rotatory dispersion and absorption

TABLE Va

Rotatory Dispersion of (+)-2-chloro-2-nitroso-apocamphane-1-carboxylic acid from the oxime in pyridine

Concentration, c = 0.0565g./5ml. : 'oxygen-free'

A = Before irradiation

B = After 300 minutes' irradiation + 9½ hours total darkness

l = 0.0995dm.

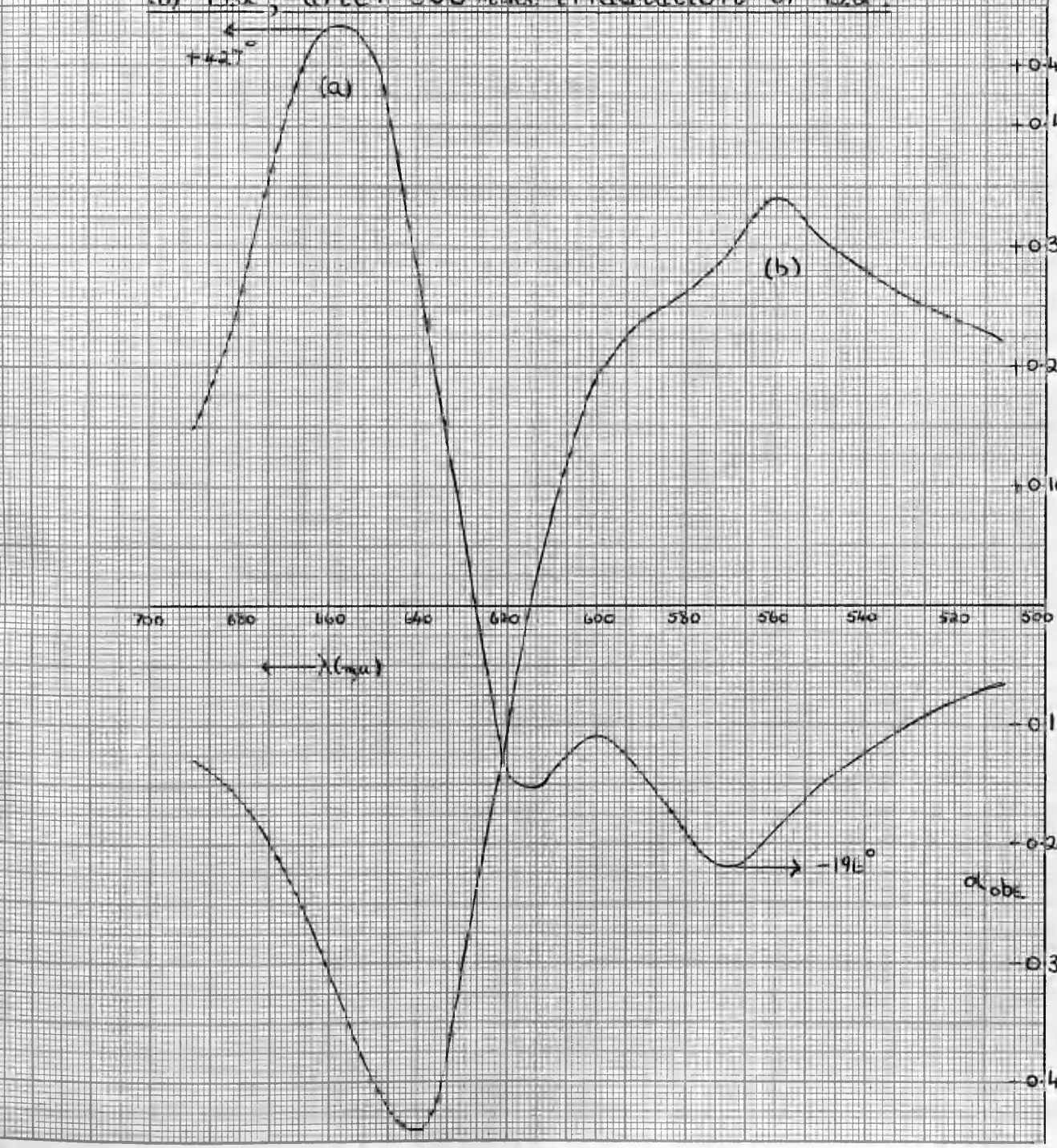
| λ(mμ.) | $\alpha_A$ | $[\alpha]_A$ | $\alpha_B$obs. |
|---|---|---|---|
| 510 | -0.07 | - 62 | +0.22 |
| 520 | -0.08 | - 71 | +0.24 |
| 530 | -0.10 | - 89 | +0.25 |
| 540 | -0.13 | -116 | +0.28 |
| 550 | -0.15 | -134 | +0.30 |
| 560 | -0.19 | -169 | +0.34 |
| 570 | -0.22 | -196 | +0.29 |
| 580 | -0.19 | -169 | +0.26 |
| 590 | -0.14 | -125 | +0.24 |
| 600 | -0.11 | - 98 | +0.19 |
| 610 | -0.14 | -125 | +0.07 |
| 620 | -0.14 | -125 | -0.10 |
| 630 | -0.01 | - 9 | -0.30 |
| 640 | +0.28 | +249 | -0.44 |
| 650 | +0.46 | +409 | -0.40 |
| 660 | +0.48 | +427 | -0.31 |
| 670 | +0.40 | +356 | -0.22 |
| 680 | +0.25 | +222 | -0.16 |
| 690 | +0.15 | +133 | -0.13 |
| 700 | Field speckled | | |

Graph IV.

# Rotatory Dispersion of

(a) (+)-2-Chloro-2-nitroso-apocamphane-1-carboxylic acid from the oxime in pyridine (B.2')

(b) B.2", after 300 mins. irradiation of B.2'.



## Irradiation of (+)-2-chloro-2-nitroso-apocamphane-1-carboxylic acid from oxime in pyridine

TABLE Vb.

Concentration, c = 0.0565g./5ml. : 'oxygen-free'.

1 = 0.0995dm. : t = 0.995cm.

Rotation-Absorption at 650mμ.

Slits:
Entrance = 1.75 Exit = 1.2 Unicam slit = 0.04mm.

| Mins. | α obs. | $\log I_o/I$ | Temp. |
|---|---|---|---|
| 0 | +0.46 | 0.816 | - |
| 90 | +0.01 | 0.73 | 21 |
| 180 | -0.24 | 0.685 | 21.5 |
| 240 | -0.35 | 0.661 | 21.5 |
| 300 | -0.40 | 0.647 | 21 |

No change in $\alpha_{obs.}$ and $\log I_o/I$ after $9\frac{1}{2}$ hours in total darkness.

Graph V.

Irradiation of

(+)-2-Chloro-2-nitroso-apocamphane-1-carboxylic acid from the oxime in pyridine (B2")

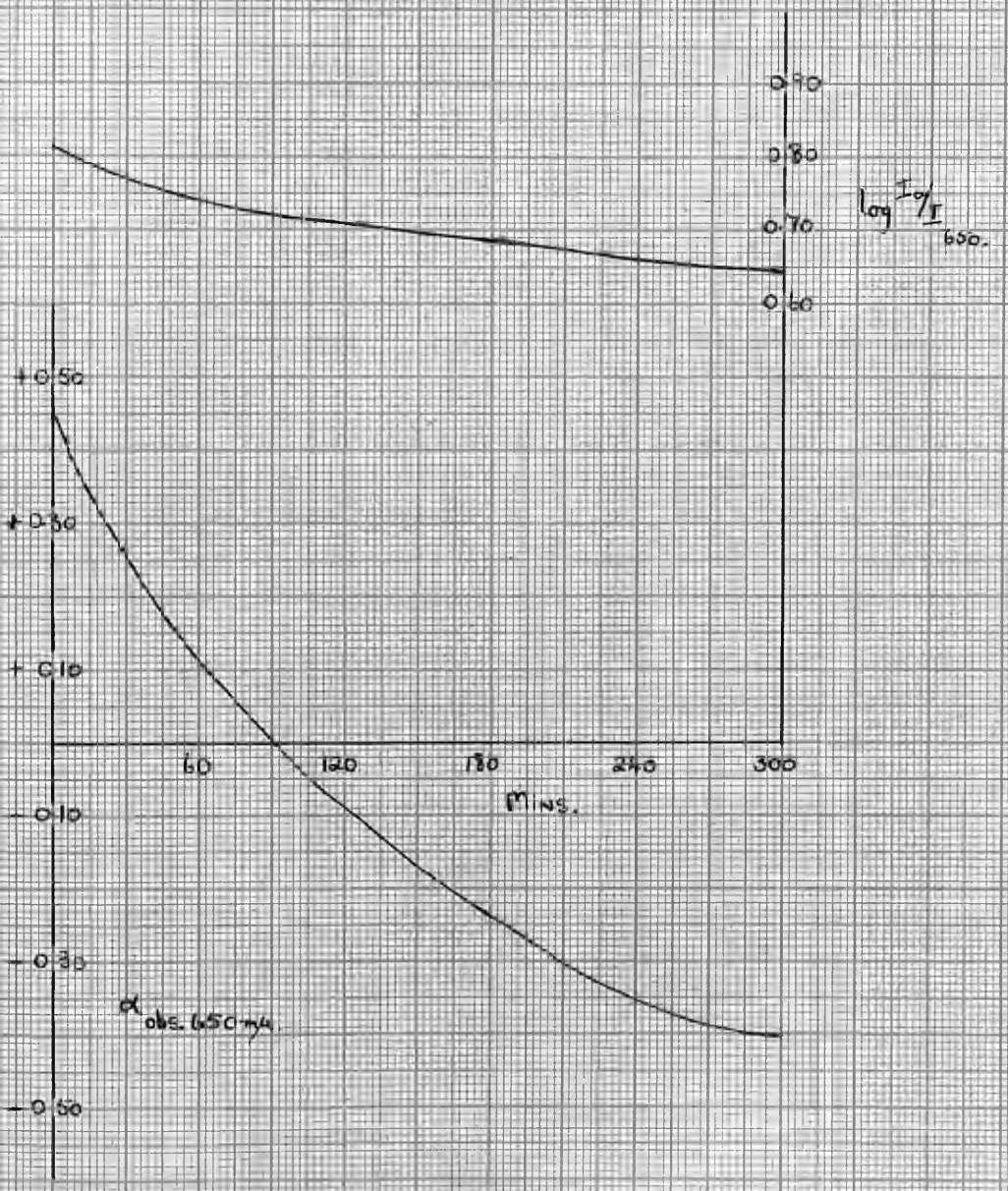


TABLE Vc

Absorption Spectrum of (+)-2-chloro-2-nitroso-apocamphane-1-carboxylic acid from the oxime in pyridine.

Concentration, as in Va, Vb.

A = Before irradiation.

B = After 300 minutes irradiation + 9½ hours total darkness.

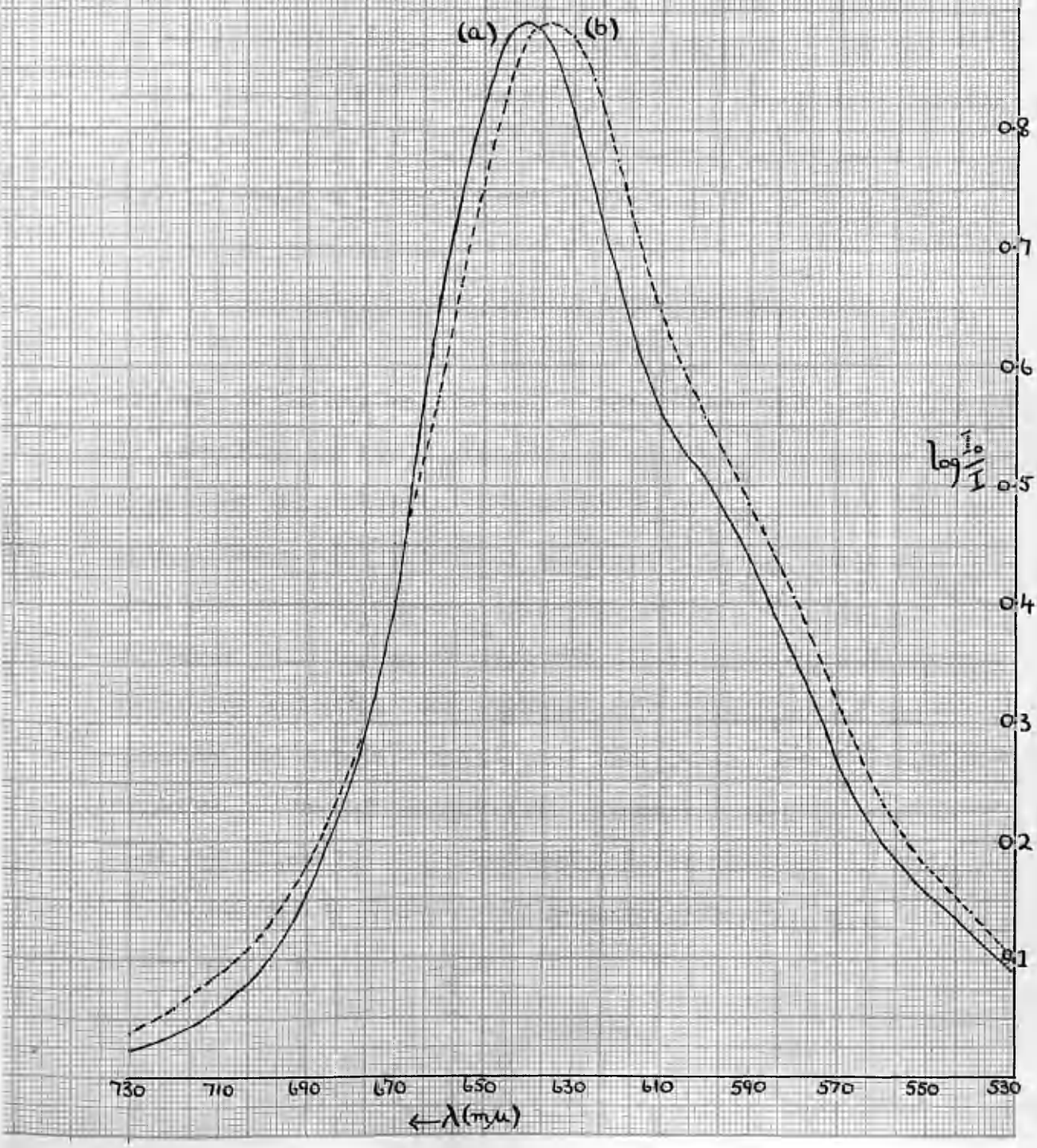
t = 0.995cm. Slit at $\lambda_{max.}$ = 0.04mm.

| λ(mμ) | $\log \frac{I_o}{I_A}$ | $\log \frac{I_o}{I_B}$ 1.168 | $\log \frac{I_o}{I_B}$ | λ(mμ) | $\log \frac{I_o}{I_A}$ | $\log \frac{I_o}{I_B}$ 1.168 | $\log \frac{I_o}{I_B}$ |
|---|---|---|---|---|---|---|---|
| 500 | 0.0335 | 0.037 | 0.032 | 615 | 0.609 | 0.710 | 0.608 |
| 504 | 0.04 | 0.041 | 0.035 | 620 | 0.680 | 0.773 | 0.662 |
| 510 | 0.05? | 0.05 | 0.043 | 625 | 0.760 | 0.841 | 0.72 |
| 514 | 0.0525 | 0.057 | 0.049 | 630 | 0.816 | 0.876 | 0.75 |
| 520 | 0.063 | 0.07 | 0.060 | 635 | 0.866 | 0.888 | 0.76 |
| 524 | 0.072 | 0.082 | 0.070 | 640 | 0.888 | 0.876 | 0.75 |
| 530 | 0.088 | 0.099 | 0.085 | 645 | 0.875 | 0.823 | 0.705 |
| 534 | 0.101 | 0.117 | 0.100 | 650 | 0.816 | 0.748 | 0.64 |
| 540 | 0.123 | 0.140 | 0.120 | 655 | 0.740 | 0.668 | 0.572 |
| 544 | 0.135 | 0.152 | 0.130 | 660 | 0.648 | 0.575 | 0.492 |
| 550 | 0.155 | 0.176 | 0.151 | 665 | 0.533 | 0.492 | 0.421 |
| 554 | 0.170 | 0.197 | 0.169 | 670 | 0.402 | 0.401 | 0.343 |
| 560 | 0.198 | 0.234 | 0.20 | 675 | 0.317 | 0.327 | 0.28 |
| 564 | 0.2165 | 0.266 | 0.228 | 680 | 0.248 | 0.319 | 0.273? |
| 568 | 0.242 | 0.299 | 0.256 | 685 | 0.198 | 0.219 | 0.188 |
| 570 | 0.265 | 0.315 | 0.270 | 690 | 0.155 | 0.179 | 0.154 |
| 574 | 0.296 | 0.352 | 0.301 | 695 | 0.120 | 0.146 | 0.125 |
| 578 | 0.337 | 0.389 | 0.333 | 700 | 0.093 | 0.120 | 0.103 |
| 580 | 0.355 | 0.405 | 0.347 | 705 | 0.074 | 0.103 | 0.088 |
| 584 | 0.390 | 0.44 | 0.377 | 710 | 0.058 | 0.089 | 0.076 |
| 588 | 0.4325 | 0.469 | 0.402 | 715 | 0.048 | 0.072 | 0.062 |
| 590 | 0.440 | 0.485 | 0.415 | 720 | 0.0365 | 0.059 | 0.051 |
| 594 | 0.474? | 0.508 | 0.435 | 725 | 0.029 | 0.050 | 0.043 |
| 598 | 0.490 | 0.537 | 0.460 | 730 | 0.024 | 0.038 | 0.0325 |
| 600 | 0.5075 | 0.558 | 0.478 | 735 | 0.018 | 0.032 | 0.0275 |
| 605 | 0.530 | 0.598 | 0.512 | 740 | 0.015 | 0.026 | 0.022 |
| 610 | 0.560 | 0.648 | 0.555 | | | | |

# Graph VI

(a) Absorption spectrum of B.2' before irradiation.

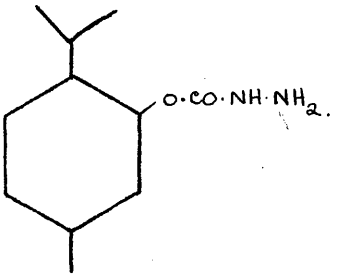
(b) " " " " after 300 mins. irradiation (rescaled to original height).



curve displacements were observed for other chloro-nitroso camphanes, and will therefore be discussed more fully later. The work described above on the blue product from the oxime in pyridine was carried out on material which had been chromatographed once. It was found that attempts to purify it further by crystallisation and passage through silica-gel columns resulted in a deterioration of the optical properties of the (+) form.

III - (+)-2-Chloro-2-nitroso-10-bromocamphane (XVI. B.3).

Two factors determined the steps by which this investigation was to proceed. These were the establishment, if possible, of the dependence of mutarotation on the nature of substituents located at $C_1$ or $C_{10}$ and the use of substituents with gradually increasing steric influence. The most natural choice, after the failure to obtain suitable derivatives of VII, was the homologous acid XXIX. This keto-acid had been synthesised by Hasselstrom and Hampton (62) (XXIV - XXIX), but the product was optically inactive. Though potentially resolvable through the carboxyl group by the usual methods, or through the ketone by Woodward's (63) l-menthyl N-aminocarbamate, this route was



at first rejected as being too long to give workable amounts of optically active acid.

Replacement of the primary bromine atom in 10-bromocamphor (XIV) appeared to offer the most direct method of preparing active 2-keto-apocamphane-1-acetic acid. The advantages of the bromo-ketone appeared to be many and are listed below:-

(a) It was easily prepared in large quantities from the starting material for B.2, viz. the active 10-sulphonic acid (II).

(b) The optical properties of its chloro-nitroso derivative (B.3) would be of great interest because of the presence of the sterically large 10-bromine atom.

(c) The substituent satisfied most of the photochemical criteria outlined in pages 26-7 , and it should be capable of replacement by groups of varying size and chemical properties, e.g. by -OH (XXIII) or by $-CH_2COOH$ (XXXI) and the homologue $-CH_2CH_2COOH$.

The unstable sulphonyl bromide (XIII), prepared from the potassium salt (XII) by grinding it with phosphorus pentabromide, was decomposed in boiling xylene to give the lachrymatory 10-bromocamphor (XIV). The oxime of XIV, prepared in pyridine according to the method of Bachmann, Cook and Lawrence (64), crystallised from ethanol in lustrous plates. Unlike the oxime of 2-keto-apocamphane-1-carboxylic acid (VIII), it was

readily soluble in ether, and chlorination at 0°C produced the deep emerald-green colour characteristic of the preparation of all chloro-nitroso compounds in ether. Removal of the solvent always gave a fairly mobile blue oil which could only be induced to solidify after passage through an activated alumina column, with petroleum ether as solvent and eluent. It was readily soluble in most solvents, but could be crystallised (lustrous plates) from petroleum ether by allowing it to stand overnight in the refrigerator. The specific rotation of this material became constant after three recrystallisations, while the melting point remained rather indefinite, shrinking at about 118°C and collapsing at 131-133°C. Analysis, however, confirmed that it was (+)-2-chloro-2-nitroso-10-bromocamphane (B.3).

The optical properties of B.3 were much superior to those of the blue carboxylic acid (B.2). The characteristics of the bromo-compound were :-

$[\alpha]_{570} = -693°$ : $[\alpha]_{660} = +832°$ : $[\alpha] \simeq o$ at $\lambda = 635 m\mu$.

$(\varepsilon_l - \varepsilon_r) = +1.11$ at $\lambda = 640 m\mu$. : $\varepsilon max. = 19.2$ at $\lambda = 650 m\mu$.

$g_o = 0.069$ at $\lambda = 630 m\mu$.

The curve of rotatory dispersion (Graph VII, Table VII) bore a striking resemblance to that for the pyridine salt (B.4), both showing a shallow 'step-in' on the longwave

side of maximum negative rotation. The absorption curve (Graph VIII, Table IX) of the bromo-compound, with its characteristic shoulder on the shortwave side of $\lambda$max., was approximately the same height as that for B.4 ($\varepsilon$max. = 19.4) but displaced some 20 mμ to the red. The symmetrical distribution of circular dichroism over the absorption range in the blue pyridine salt was not repeated with the bromo-camphane, for which a plot of ($\varepsilon_l - \varepsilon_r$) against $\lambda$ revealed a shift of 10 mμ to the blue (Graph VIII, Table VI). A similar effect had been observed with the parent blue camphane (B.1), but in the opposite direction. The values of 'g', the anisotropy factor, are tabulated in Table VI and illustrated in Graph VIII. The shallow trough between 590 and 610 mμ corresponded roughly to the shoulder on the absorption curve. The compression of the dichroism curve to shorter wavelengths accounted for the relatively high values of 'g' as the extinction coefficients decreased rapidly.

Solutions of 2-chloro-2-nitroso-10-bromocamphane in absolute ethanol, which had been freed as much as possible from dissolved oxygen by distillation under an atmosphere of nitrogen, were irradiated in sealed glass tubes suspended in a large glass tank through which water

TABLE VI

Ellipticity, Circular Dichroism and Anisotropy Factors of (+)-2-chloro-2-nitroso-10-bromocamphane

Concentration, c = 0.0305g./5ml. : 'oxygen-free'.

Mol. Wt. = 280.61 : M = 0.02174 : l = 2.5cm.

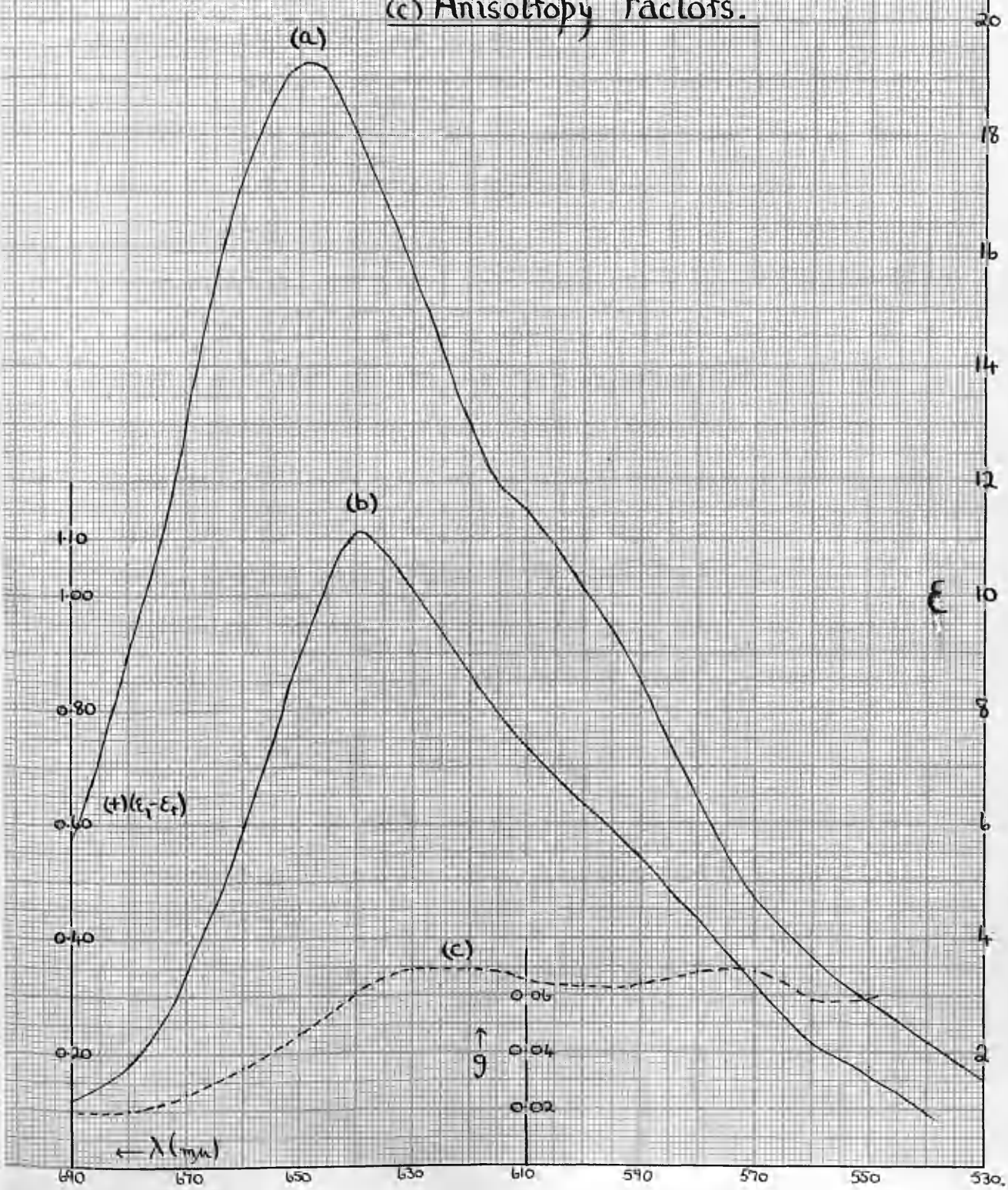
| $\lambda$(mμ.) | $+\phi$ | $+(\varepsilon_l - \varepsilon_r)$ | g |
|---|---|---|---|
| 530 | 0.10 | 0.056 | 0.037 |
| 540 | 0.16 | 0.089 | 0.041 |
| 550 | 0.31 | 0.173 | 0.059 |
| 560 | 0.38 | 0.212 | 0.058 |
| 570 | 0.57 | 0.318 | 0.068 |
| 580 | 0.78 | 0.435 | 0.068 |
| 590 | 0.97 | 0.541 | 0.064 |
| 600 | 1.13 | 0.631 | 0.063 |
| 610 | 1.32 | 0.737 | 0.065 |
| 620 | 1.61 | 0.898 | 0.069 |
| 630 | 1.92 | 1.07 | 0.069 |
| 640 | 1.99 | 1.11 | 0.061 |
| 650 | 1.61 | 0.898 | 0.047 |
| 660 | 1.07 | 0.597 | 0.035 |
| 670 | 0.61 | 0.340 | 0.026 |
| 680 | 0.32 | 0.179 | 0.020 |
| 690 | 0.21 | 0.117 | 0.020 |
| 700 | 0.19 | 0.106 | 0.029 |

Graph VIII.

(+)-2-Chloro-2-nitroso-10-bromocamphane (B.3).

(a) Absorption Spectrum. (b) Circular Dichroism.

(c) Anisotropy Factors.



circulated. Continuous exposure to the light from six 100 watt bulbs resulted in the complete disappearance of the blue colour in about one month. Removal of the solvent, which contained free hydrochloric acid (silver nitrate) and acetaldehyde (apple smell - no attempt was made to form a dimedone derivative) gave a small amount of sticky brown solid which, after several crystallisations from ethanol, was positively identified as 10-bromocamphor oxime (XV) (mixed melting point). It should be noted at this point that XV did not form an oxime hydrochloride under the usual conditions, namely the passage of dry hydrogen chloride into an ethereal solution of oxime, so that the identification of a photolysis product as free oxime was not unexpected. The amount of rotation induced by asymmetric decomposition of the blue bromo-compound was calculated by means of Kuhn's equation, viz.

$$\alpha' = \alpha. \frac{g.}{2} (1-\beta). \log \frac{1}{1-\beta.}$$

Thus, using a 5% solution in a 1dm. tube, the rotation developed ($\alpha'$) at 530mμ. for 60% decomposition should be approximately

$$\alpha' = \frac{36.5}{1.45} \times 0.069 \times 0.2 \times 0.3979$$

$$= 0.14°$$

In all these respects, then, B.3 was as suitable as the pyridine salt for asymmetric photolysis and possessed the added advantages that a product of photodecomposition had been identified and thus showed that it did not contain an unstable group (except that on $C_2$) comparable with the pyridinium nucleus in B.4.

These properties, however, would be vitiated by mutarotation under the influence of red light. The irradiation of (+)-2-chloro-2-nitroso-10-bromocamphane, under conditions identical with those for B.2 and B.2', was carried out to establish this point. The results for this are set out in Tables VII, VIII, IX (Graphs VII, IX, X). The importance of spectrophotometric methods in following the course of irradiation had been emphasised by the 'band-shifts' observed by Hope in (+)-2-chloro-2-nitroso-pinane and in the previous carboxylic acid (B.2, B.2'), so that the optimum concentration for absorption measurements was used. This was made possible by the large rotations of the blue bromo-camphane. A plot of observed rotation against time (Graph IX) showed a fairly slow fall in the first three hours. After 744 minutes, the rotation had changed by about 76% and appeared to be approaching the axis of zero rotation without changing sign. This was unlike both the parent

compound (B.1) and 2-chloro-2-nitroso-apocamphane-1-carboxylic acid, where α had changed sign after short exposure (60 minutes, ca.), but was analogous to the pyridine salt (B.4). The effect shown by the latter compound had, in the absence of absorption measurements, been interpreted as a decrease in rotation due entirely to simple photolysis uncomplicated by 2:2'- mutarotation. In the case of the bromo-compound, however, the curves of $\alpha^{660}$ observed against time, and $\log \frac{I_o}{I}_{660}$ against time (plotted on the same scale as the rotation curve, so that the percentage changes per scale unit were the same) showed a complete lack of parallelism ($\log \frac{I_o}{I}_{660}$ changed 26.5% in 744 minutes), and indicated that the change in rotation must be a multiple process. This was substantiated by the determination of the curve of rotatory dispersion (Table VII Graph VII) after 1022 minutes' irradiation, when a displacement of 10mμ (ca.) to longer wavelengths was observed. The curves for the mutarotating camphanes B.1 and B.2' also showed this effect. The experimental determination of the absorption spectrum after irradiation (480 minutes, 21.4% change in $\log \frac{I_o}{I}_{660}$) revealed a displacement of λ max. from 650mμ to 660mμ and increases in $\log I_o/I$ (14% at λ = 685mμ) on the longwave side of λ max. All readings on the shortwave side were smaller than the

TABLE VII

Rotatory Dispersion of (+)-2-chloro-2-nitroso-10-bromo-camphane, before and after irradiation

Concentration, c = 0.0725g./5ml. : 'oxygen-free'.

l = 0.0995dm.

$\alpha_o$ = rotation before irradiation.

$\alpha_{1022}^{obs.}$ = rotation after 1022 mins. + 85½ hours in darkness.

| λ(mμ.) | $\alpha_o$ | $[\alpha]_o$ | $\alpha_{1022}^{obs.}$ |
|---|---|---|---|
| 500 | -0.57 | -395 | - |
| 510 | -0.61 | -423 | - |
| 520 | -0.67 | -464 | -0.35 |
| 530 | -0.73 | -506 | - |
| 540 | -0.80 | -554 | -0.41 |
| 550 | -0.84 | -582 | - |
| 560 | -0.95 | -658 | -0.49 |
| 570 | -1.00max. | -693 | -0.52 |
| 580 | -0.98 | -679 | -0.55max. |
| 590 | -0.89 | -617 | -0.52 |
| 600 | -0.80 | -554 | - |
| 610 | -0.74 | -513 | -0.48 |
| 620 | -0.59 | -409 | - |
| 630 | -0.28 | -194 | -0.32 |
| 640 | +0.30 | +208 | -0.12 |
| 650 | +0.91 | +631 | +0.10 |
| 660 | +1.20max. | +832 | +0.28 |
| 670 | +1.16 | +804 | +0.37 |
| 680 | +0.99 | +686 | +0.42max. |
| 690 | +0.79 | +547 | +0.41 |
| 700 | +0.66 | +457 | - |

# Graph VII

## Rotatory Dispersion of (+)-2-chloro-2-nitroso-10-bromo-camphane.

(a) Before irradiation.

(b) After 1022 mins. + 85½ hours darkness.

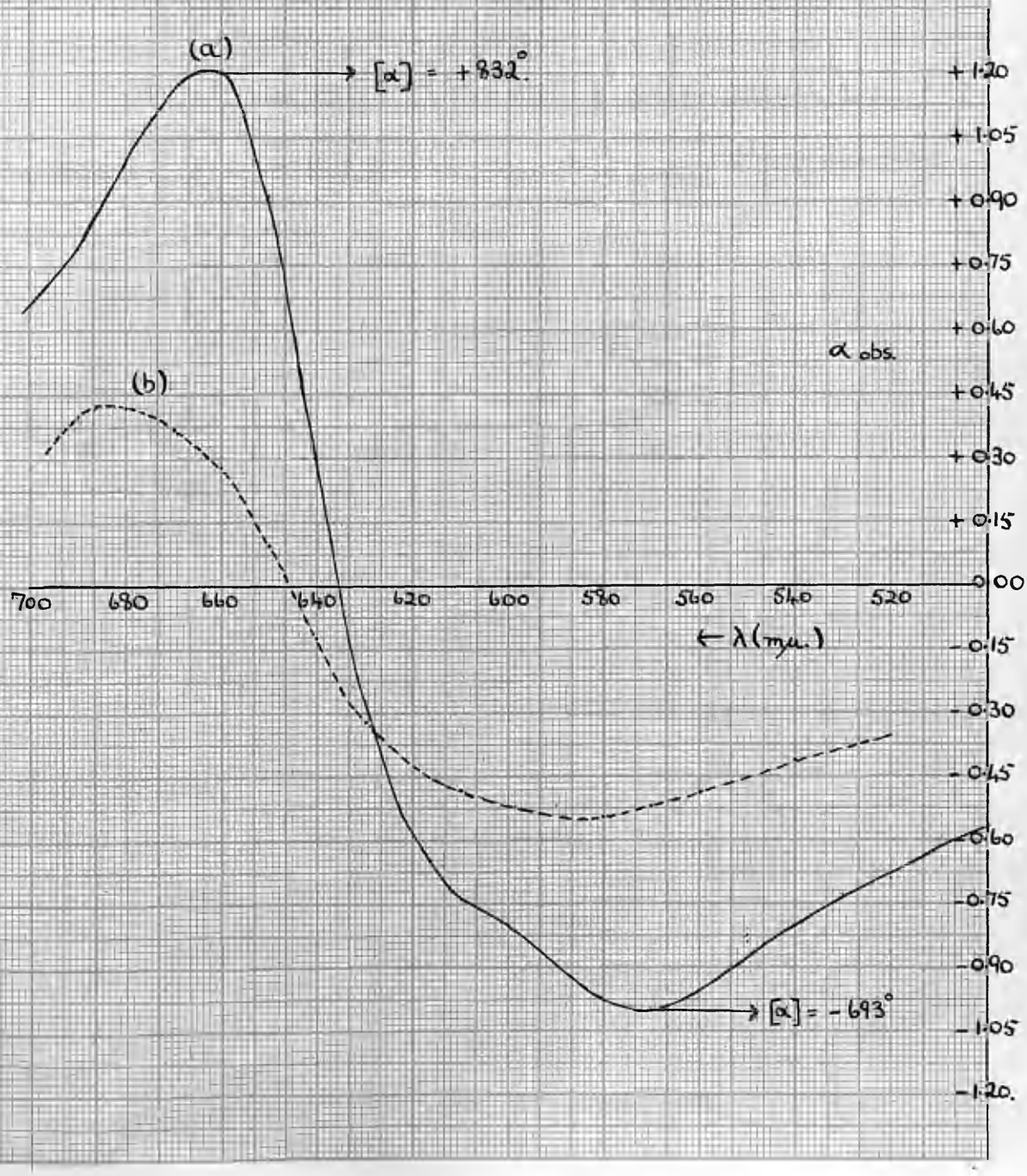


TABLE VIII

Irradiation of (+)-2-chloro-2-nitroso-10-bromocamphane

Concentration, c = 0.0725g./5ml. : 'oxygen-free'.

l = 0.0995dm. : t = 0.995cm.

Rotation-Absorption at 660mμ.

Unicam slit = 0.04mm.

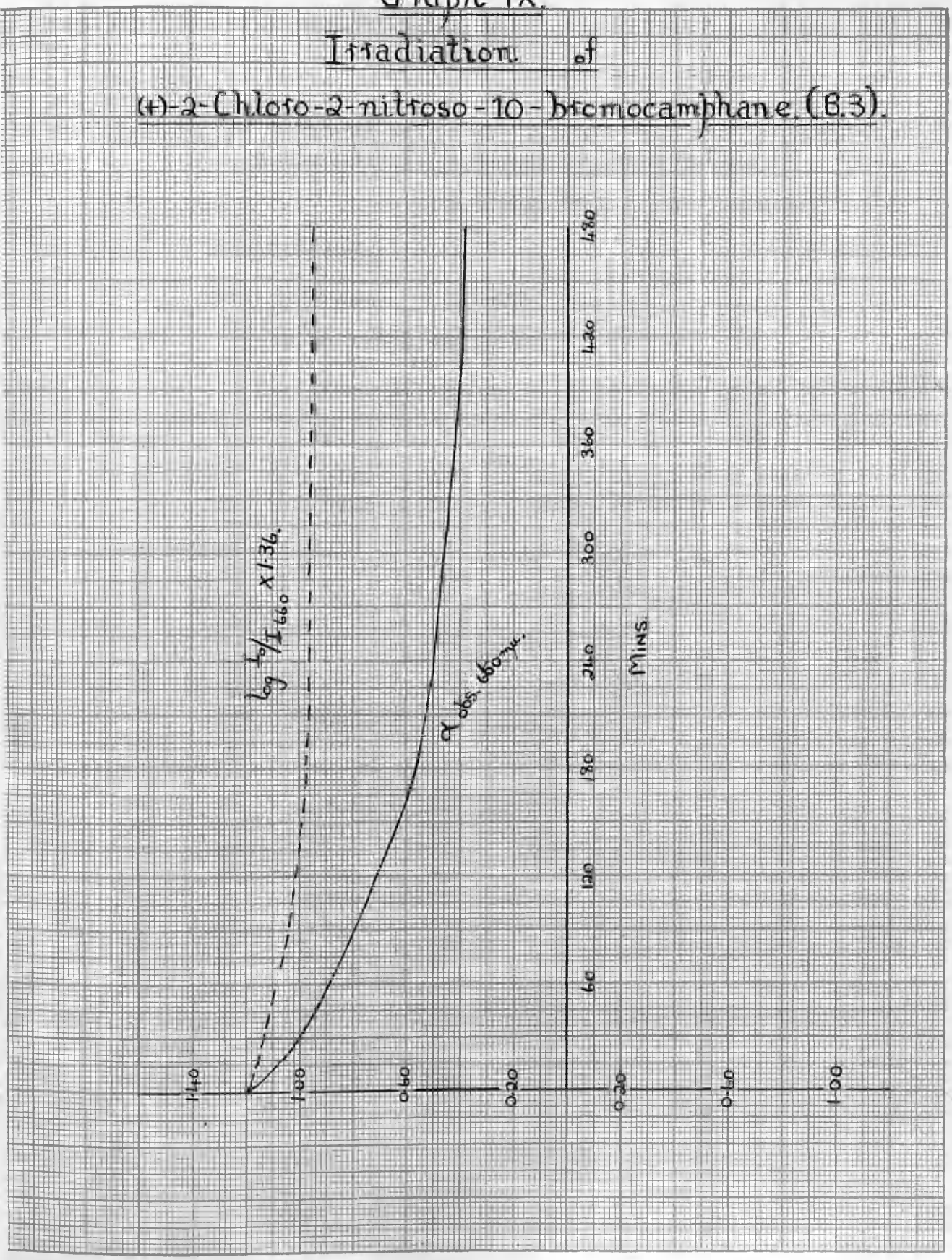
Slits: Rotation: Entrance = 1.75 Exit = 1.4

| Mins. | $\alpha_{obs.}$ | $\log \frac{I_o}{I}$ | $\log {}^{I_o}/_{I}$ x 1.36 | Temp. |
|---|---|---|---|---|
| 0 | +1.20 | 0.882 | 1.20 | 20 |
| 30 | +1.00 | 0.83 | 1.13 | 20.5 |
| 60 | +0.89 | 0.808 | 1.09 | 21 |
| 120 | +0.70 | 0.775 | 1.05 | 22 |
| 180 | +0.56 | 0.758 | 0.97 | 23 |
| 480 | +0.38 | 0.692 | 0.941 | 22 |
| No change after 11 hrs. in darkness | | | | |
| 744 | +0.31 | 0.648 | 0.882 | 22.5 |

Graph IX.

Irradiation of

(+)-2-Chloro-2-nitroso-10-bromocamphane (B.3).



## TABLE IX

### Absorption Spectrum of (+)-2-chloro-2-nitroso-10-bromo-camphane before and after irradiation

Concentration, c = 0.0725g./5ml. : 'oxygen-free'.

M = 0.05167 : t = 0.995cm. : Mol. Wt. = 280.61

Slit at $\lambda$max. = 0.04mm.

A = Before irradiation

B = After 480 mins. + 11 hours in total darkness

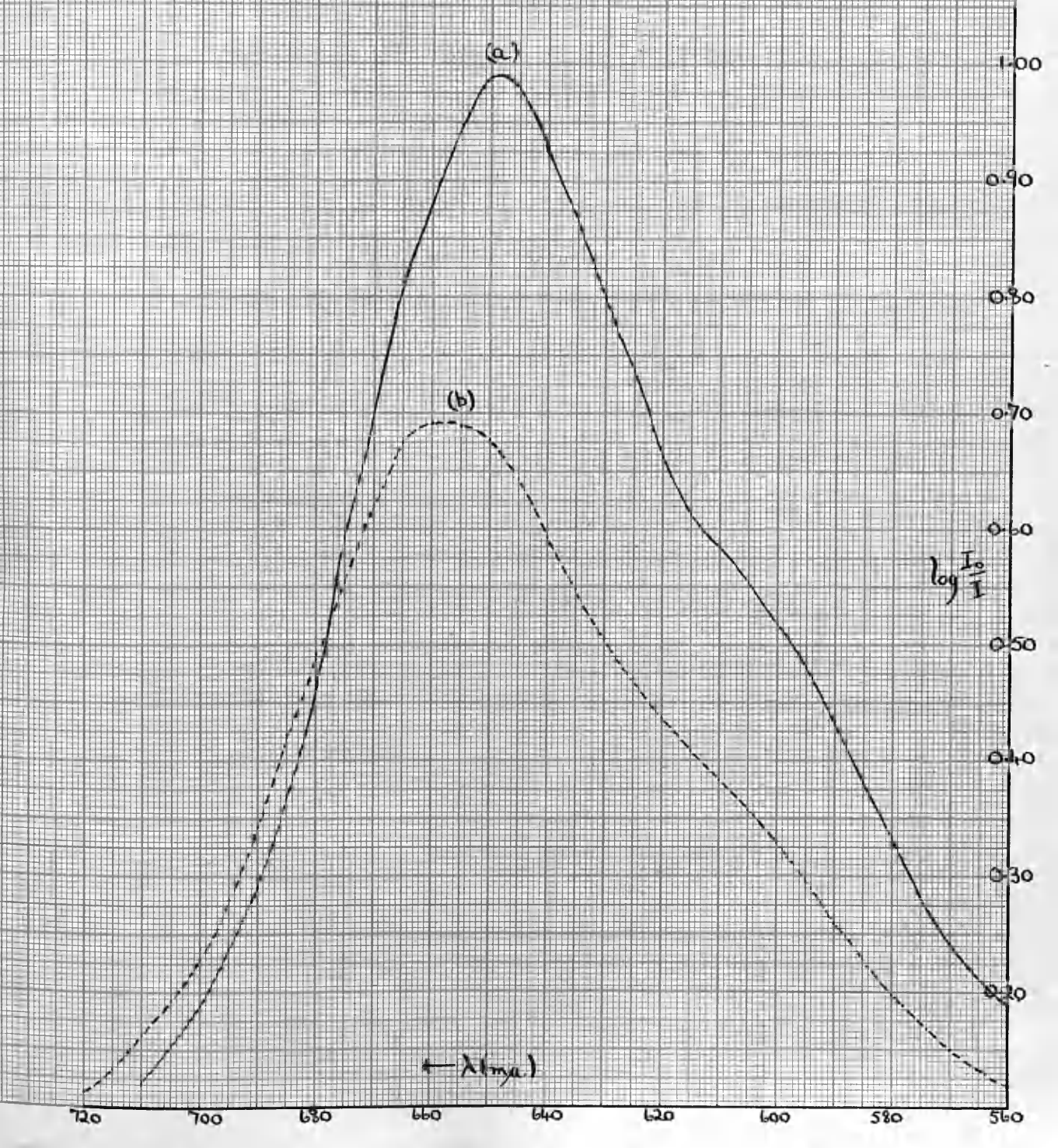
| $\lambda$(mμ) | $\varepsilon_A$ | $\log \frac{I_o}{I_A}$ | $\log \frac{I_o}{I_B}$ | $\lambda$(mμ) | $\varepsilon_A$ | $\log \frac{I_o}{I_A}$ | $\log \frac{I_o}{I_B}$ |
|---|---|---|---|---|---|---|---|
| 500 | 0.52 | 0.0265 | 0.0177 | 620 | 12.9 | 0.668 | 0.436 |
| 504 | 0.62 | 0.0318 | 0.020 | 625 | 14.4 | 0.738 | 0.470 |
| 510 | 0.77 | 0.0395 | 0.025 | 630 | 15.6 | 0.800 | 0.505 |
| 514 | 0.86 | 0.045 | 0.028 | 635 | 16.9 | 0.87 | 0.548 |
| 520 | 1.06 | 0.0545 | 0.0345 | 640 | 18.1 | 0.93 | 0.593 |
| 524 | 1.20 | 0.0618 | 0.039 | 645 | 19.1 | 0.980 | 0.643 |
| 530 | 1.51 | 0.0775 | 0.0465 | 650 | 19.2 | 0.988 | 0.676 |
| 534 | 1.79 | 0.0918 | 0.053 | 655 | 18.5 | 0.949 | 0.688 |
| 540 | 2.19 | 0.1125 | 0.066 | 660 | 17.2 | 0.882 | 0.69 |
| 544 | 2.49 | 0.128 | 0.0755 | 665 | 15.8 | 0.813 | 0.675 |
| 550 | 2.898 | 0.149 | 0.092 | 670 | 13.0 | 0.67 | 0.620 |
| 554 | 3.19 | 0.164 | 0.102 | 675 | 10.7 | 0.548 | 0.554 |
| 560 | 3.67 | 0.1885 | 0.1195 | 680 | 8.95 | 0.460 | 0.493 |
| 564 | 4.01 | 0.206 | 0.130 | 685 | 7.19 | 0.370 | 0.422 |
| 570 | 4.69 | 0.241 | 0.150 | 690 | 5.77 | 0.2965 | 0.344 |
| 574 | 5.29 | 0.272 | 0.168 | 695 | 4.62 | 0.2375 | 0.280 |
| 578 | 6.03 | 0.310 | 0.188 | 700 | 3.64 | 0.187 | 0.228 |
| 580 | 6.42 | 0.330 | 0.199 | 705 | 2.95 | 0.1518 | 0.1925 |
| 584 | 7.19 | 0.370 | 0.222 | 710 | 2.33 | 0.120 | 0.163 |
| 588 | 8.07 | 0.415 | 0.249 | 715 | 1.85 | 0.095 | 0.133 |
| 590 | 8.46 | 0.435 | 0.260 | 720 | 1.51 | 0.0775 | 0.1125 |
| 594 | 9.22 | 0.474 | 0.290 | 725 | 1.19 | 0.0612 | 0.095 |
| 598 | 9.84 | 0.506 | 0.316 | 730 | 0.97 | 0.050 | 0.080 |
| 600 | 10.1 | 0.519 | 0.330 | 735 | 0.79 | 0.041 | 0.067 |
| 605 | 10.8 | 0.555 | 0.357 | 740 | 0.64 | 0.033 | 0.055 |
| 610 | 11.4 | 0.585 | 0.384 | 745 | 0.51 | 0.026 | 0.0465 |
| 615 | 11.9 | 0.612 | 0.408 | | | | |

Graph X (also Graph VIII)

(+)-2-Chloro-2-nitroso-10-bromocamphane (B.3).

(a) Absorption Spectrum before irradiation.

(b) " " after 480 mins + 11 hours dark.



starting values (Table IX, Graph X). It should be noted that the bodily movement of the vibrational-band envelope for B.2' was shown only after re-scaling to the original height.

Although irradiation of B.3 did not result in the inversion of the Cotton effect these three facts, the non-parallel curves of $\alpha_{obs.}$-time and $\log I_o/I$-time; the displacement of the curve of rotatory dispersion; the shift of the absorption maximum and the increase in $\log I_o/I$ at long-wavelengths, made it clear that photolysis did not yield directly, products absorbing outwith the visible spectrum. Moreover, these results warranted a reinvestigation of the pyridine salt of (+)-2-chloro-2-nitroso-camphane-10-sulphonic acid which had been stated to be free from 'photo-mutarotation' by Mitchell and Watson (50), solely on the basis that irradiation did not produce an inversion of the curve of rotatory dispersion. The absorption spectrum was not examined after irradiation.

## IV - The reinvestigation of the pyridine salt of (+)-2-chloro-2-nitrosocamphane-10-sulphonic acid(B.4) and attempts to obtain the free acid (B.5).

The pyridine salt of (+)-2-chloro-2-nitrosocamphane-

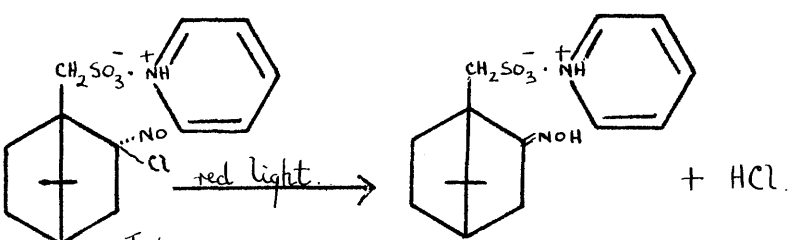
10-sulphonic acid was prepared according to the method of Mitchell and Watson (59). Slow chlorination of the sulphonic acid oxime (III) dissolved in pure, anhydrous pyridine at about -15°C., resulted in the precipitation of the deep blue pyridine salt (10 minutes, ca.). This was filtered, washed with ether to remove the excess of pyridine and dried on porous plate. Crystallisation from absolute ethanol gave beautiful, long needles of the salt melting at 152-153°C with decomposition. The extremely low solubility of this material in all organic solvents forced the above authors to use a dilute solution, whose concentration gave a value of $\log I_o/I$ at $\lambda$max. of about 0.45. The determination of the complete absorption spectrum of this solution after 30% photolysis would have tended, therefore, to be inaccurate. Solution of larger amounts in the same volume of solvent was effected by grinding the crystalline salt in an agate mortar and warming the solution in a water bath at about 45°C. The flask was given ample time to reach room temperature before making up to the mark.

The irradiation of B.4 was carried out in the same cell and under exactly the same conditions as for B.2, B.2' and B.3. The result obtained by plotting the observed fall in rotation at 655 against time (Graph XI, Table X)

was essentially the same as Watson's, namely the slow approach to the axis of zero rotation without change of sign. As in the blue bromo-camphane, however, the first indications of the presence of a second photochemical process were the non-superposition of the curve of $\log I_o/I$ at 630mμ. against time (on the same scale as the rotation-time curve, so that the percentage change per scale unit was the same) and the uneven variation of $\log I_o/I$ at 655mμ. (Table X) during the irradiation. The absorption spectrum, determined after 271 minutes of irradiation ($\log I_o/I$ at 630mμ. had decreased by about 30%) revealed a displacement of λmax. from 630mμ to 635mμ. and, as in the bromo-substituted camphane, large increases in the values of $\log I_o/I$ on the long-wave side of λmax. All readings on the short-wave side were smaller than the starting values (Graph XII, Table XI). Continued irradiation (total time, 516 minutes) resulted in a further decrease in absorption in the range 675-500mμ, while the values at 680-720mμ remained practically stationary and were further proof of the presence of two photochemical processes. On the basis of these results, it was concluded that the blue pyridine salt,

like (+)-2-chloro-2-nitroso-10-bromocamphane, was subject to at least two reactions on irradiation, at least one of which contributed to the absorption in the visible spectrum.

The change in the spectrum of the pyridine salt presented a difficulty not present in B.1, 2, 2' or 3. It might be argued that the band-shift was due to the presence of increasing amounts of chloro-nitroso sulphonic acid (B.5), liberated from the salt by hydrochloric acid produced by photolysis of the chloro-nitroso group on $C_2$. To elucidate this point, the spectrum of the salt, dissolved in absolute ethanol containing hydrochloric acid, was carefully determined at various intervals. The amount of hydrochloric acid used corresponded to an excess greater than that produced by 100% decomposition according to the following postulated reaction sequence:




The values of $\log I_o/I$ at a selection of wavelengths covering the absorption range remained unchanged (within experimental error) after 21 hours (Table XII). There

## TABLE X

### Irradiation of the pyridine salt of (+)-2-chloro-nitroso-camphane-10-sulphonic acid

Concentration, c = 0.0769g./5ml. : 'oxygen-free'.

l = 0.0995dm. : t = 0.995cm.

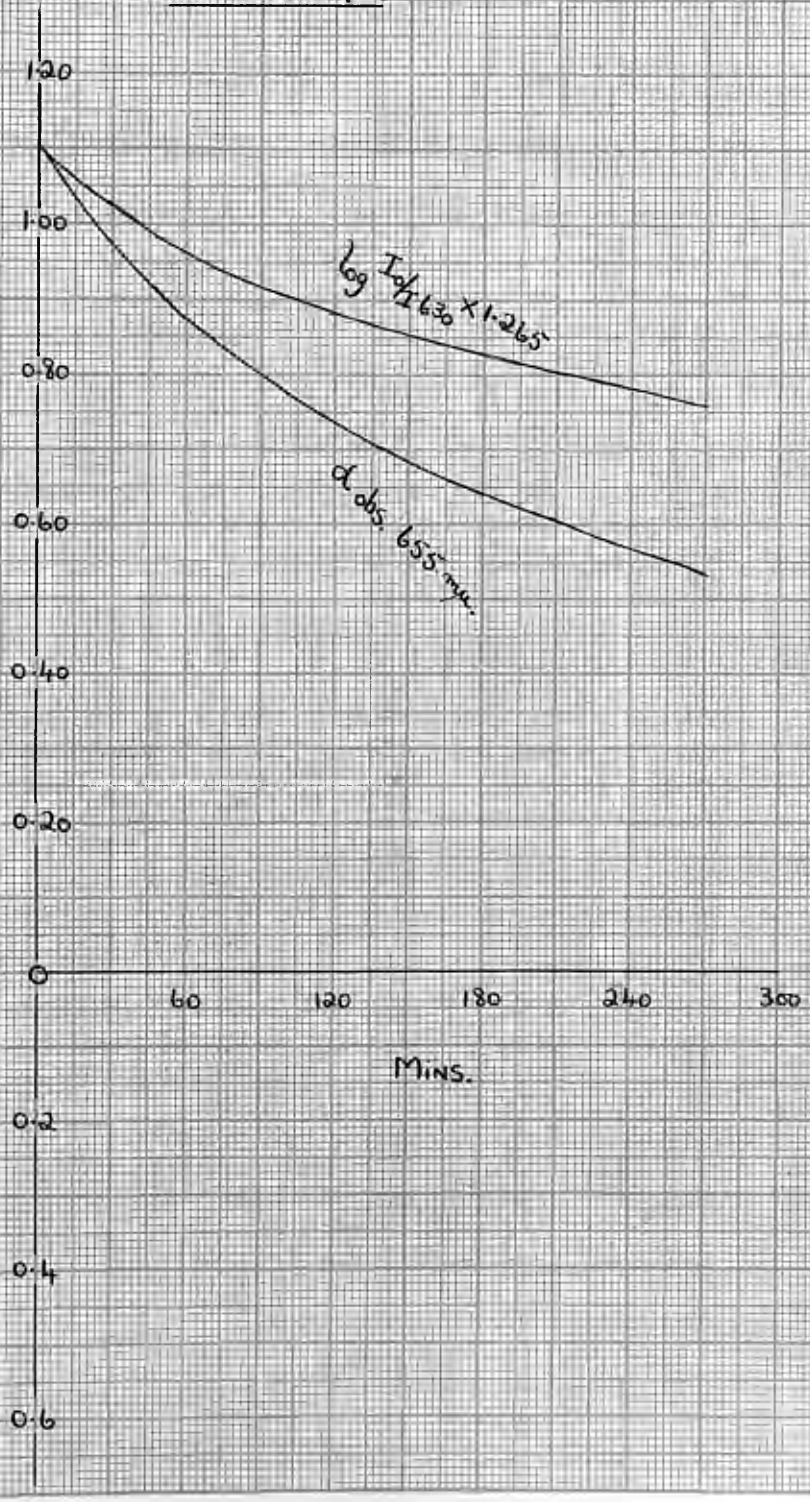
Rotation (655mμ)-Absorption (655-630mμ)

Slits : Rotation : Entrance = 1.8 Exit = 0.9
Absorption : 0.04125mm. at 655mμ.
0.054mm. at 630mμ.

| Mins. | α obs. | $\log \frac{I_o}{I_{630}}$ | $\log \frac{I_o/I_{630}}{1.265}$ | $\log \frac{I_o}{I_{655}}$ | Temp. |
|---|---|---|---|---|---|
| 0 | +1.10 | 0.87 | 1.10 | 0.532 | 18.75 |
| 30 | +0.97 | - | - | 0.525 | 19.2 |
| 60 | +0.87 | 0.76 | 0.961 | 0.530 | 20 |
| 151 | +0.68 | 0.673 | 0.851 | 0.542 | 21 |
| 271 | +0.53 | 0.601 | 0.760 | 0.532 | 21.8 |
| | No change after 13½ hours in darkness | | | | |
| 516 | +0.41 | 0.522 | 0.660 | 0.49 | 21.8 |

# Graph XI.

## Irradiation of the pyridine salt of (+)-2-Chloro-2-nitrosocamphane-10-sulphonic acid. (B.4).



## TABLE XI

**Absorption Spectrum of the pyridine salt of (+)-2-chloro-2-nitrosocamphane-10-sulphonic acid before and after irradiation**

Concentration, c = 0.0769g./5ml. : 'oxygen-free'.

t = 0.995cm. : Mol. Wt. = 360.87

A = Before irradiation : Slit at $\lambda$max. = 0.049mm.

B = After 271 minutes : Slit at $\lambda$max. = 0.041mm.

C = After 561 minutes.

| $\lambda$(mμ) | $\log \frac{I_o}{I_A}$ | $\log \frac{I_o}{I_B}$ | $\log \frac{I_o}{I_c}$ | $\lambda$(mμ) | $\log \frac{I_o}{I_A}$ | $\log \frac{I_o}{I_B}$ | $\log \frac{I_o}{I_c}$ |
|---|---|---|---|---|---|---|---|
| 500 | 0.0425 | 0.030 | - | 610 | 0.675 | 0.472 | 0.411 |
| 504 | 0.048 | 0.034 | - | 615 | 0.740 | 0.51 | 0.442 |
| 510 | 0.0575 | 0.041 | - | 620 | 0.800 | 0.552 | 0.474 |
| 514 | 0.0695 | 0.0455 | - | 625 | 0.85 | 0.585 | 0.505 |
| 520 | 0.085 | 0.054 | 0.056? | 630 | 0.87 | 0.601 | 0.522 |
| 524 | 0.0972 | 0.0625 | - | 635 | 0.860 | 0.615 | 0.5375 |
| 530 | 0.118 | 0.076 | 0.073 | 640 | 0.812 | 0.608 | 0.5375 |
| 534 | 0.134 | 0.085 | - | 645 | 0.735 | 0.593 | 0.529 |
| 540 | 0.1565 | 0.101 | 0.095 | 650 | 0.632 | 0.562 | 0.515 |
| 544 | 0.1725 | 0.110 | - | 655 | 0.532 | 0.532 | 0.49 |
| 550 | 0.1925 | 0.130 | 0.1175 | 660 | 0.4275 | 0.489 | 0.457 |
| 554 | 0.220 | 0.1435 | - | 665 | 0.338 | 0.447 | 0.428 |
| 560 | 0.260 | 0.1715 | 0.1525 | 670 | 0.268 | 0.397 | 0.386 |
| 564 | 0.30? | 0.1925 | 0.171 | 675 | 0.211 | 0.355 | 0.3475 |
| 568 | 0.330 | 0.214 | - | 680 | 0.173 | 0.307 | 0.308 |
| 570 | 0.352 | 0.225 | 0.200 | 685 | 0.134 | 0.262 | 0.259 |
| 574 | 0.394 | 0.249 | 0.219 | 690 | 0.1045 | 0.217 | 0.218 |
| 578 | 0.432 | 0.274 | 0.237 | 695 | 0.0835 | 0.177 | - |
| 580 | 0.448 | 0.283 | 0.248? | 700 | 0.0635 | 0.144 | 0.1455 |
| 584 | 0.480 | 0.309 | 0.265 | 705 | 0.050 | 0.121 | 0.123 |
| 588 | 0.508 | 0.330 | 0.287 | 710 | 0.041 | 0.101 | 0.1025 |
| 590 | 0.5175 | 0.342 | 0.295 | 715 | 0.032 | 0.086 | 0.087 |
| 594 | 0.540 | 0.365 | 0.320 | 720 | 0.025 | 0.070 | 0.0715 |
| 598 | 0.568 | 0.390 | 0.340 | 725 | - | 0.0565 | - |
| 600 | 0.585 | 0.402 | 0.350 | 730 | - | 0.050 | - |
| 605 | 0.625 | 0.435 | 0.3775 | 735 | - | 0.042 | - |

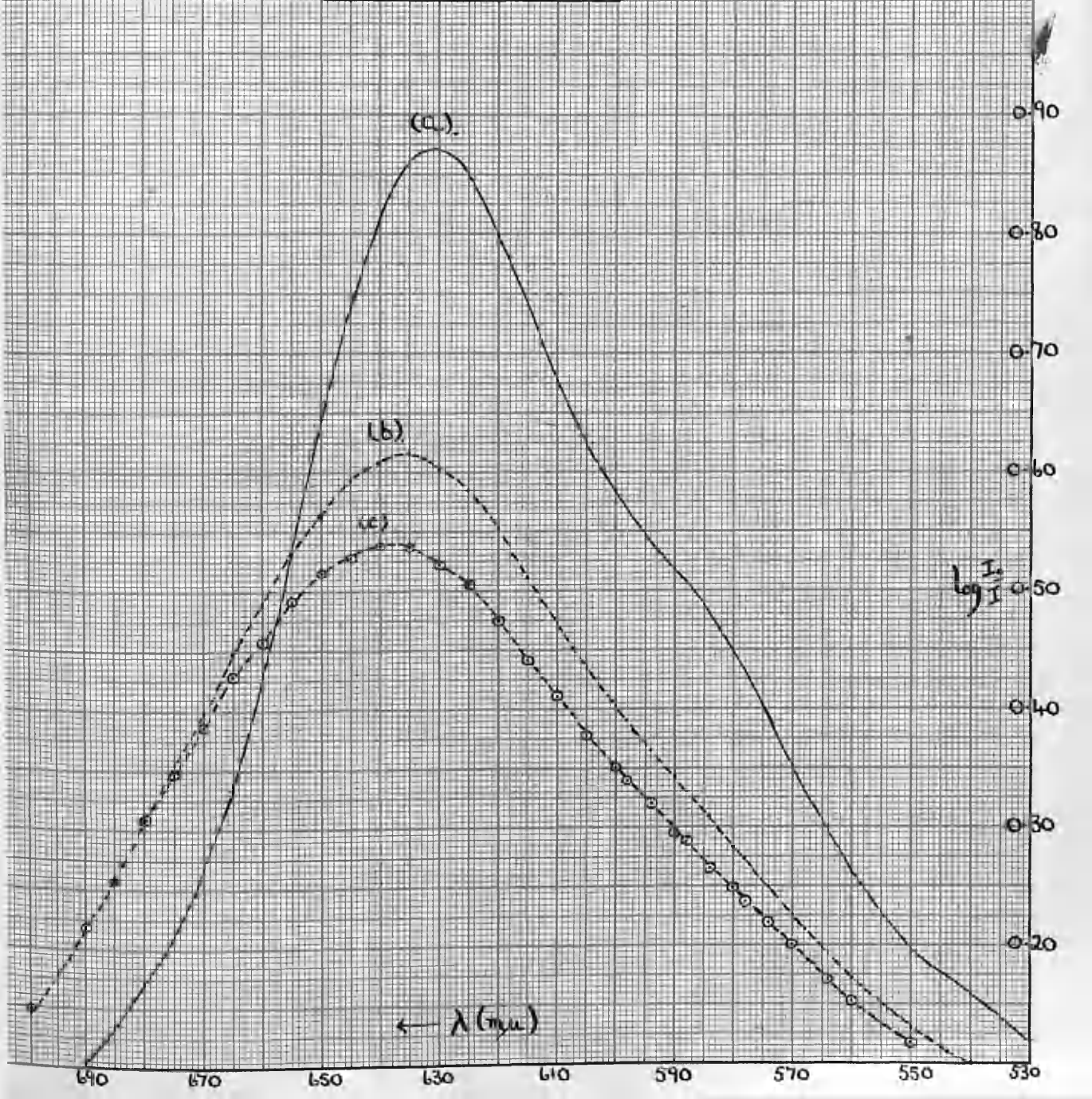
# Graph XII

## Absorption spectrum of the pyridine salt of (+)-2-chloro-2-nitrosocamphane-10-sulphonic acid (B.L.).

(a) Before irradiation.

(b) After 271 mins.

(c) " 516 mins.



## TABLE XII

The effect of hydrochloric acid on the spectrum of the pyridine salt of (+)-2-chloro-2-nitroscamphane-10-sulphonic acid

Concentration, c = 0.0763g./5ml. absolute ethanol containing 16mg. (ca.) HCl/10ml.

t = 0.995cm.

| λ(mμ.) | Minutes | | | |
|---|---|---|---|---|
| | 0 | 120 | 454 | 1264 |
| 580 | 0.445 | 0.445 | 0.441 | 0.44 |
| 590 | 0.508 | 0.508 | 0.506 | 0.505 |
| 600 | 0.572 | 0.572 | 0.572 | 0.57 |
| 625 | 0.838 | 0.838 | 0.83 | 0.83 |
| 630 | 0.858 | 0.858 | 0.85 | 0.85 |
| 635 | 0.850 | 0.845 | 0.84 | 0.835 |
| 640 | 0.806 | 0.800 | 0.798 | 0.79 |
| 665 | 0.331 | 0.338 | 0.337 | 0.327 |
| 670 | 0.263 | 0.264 | 0.263 | 0.260 |
| 680 | 0.168 | 0.168 | 0.165 | 0.1645 |
| 690 | 0.1045 | 0.1045 | 0.104 | 0.100 |

was no displacement in the position of $\lambda$max. It was concluded, therefore, that the changes observed on irradiation of the blue salt were due neither to the formation of non-isomeric blue acid (i.e. B.5) nor to a change in the medium. The results from the above experiment can be equally well applied to the other chloro-nitroso camphanes.

The removal of the pyridinium nucleus in B.4 to give the free sulphonic acid involved a large alteration in the size and nature of the substituent located at $C_{10}$. Two distinct methods of effecting this were attempted. Chlorination of a rapidly stirred suspension of the oxime (III) in a large volume of ether for several hours yielded no trace of the chloro-nitroso sulphonic acid. The free acid, prepared by dissolving the blue salt in concentrated hydrochloric acid, could not be purified ( Watson). The passage of an aqueous solution of the pyridine salt through a column of ion-exchange resin (Dowex IR 400(H)) resulted in the complete exchange of pyridine. Shaking with octyl alcohol partially separated the blue acid, but removal of the solvent under reduced pressure resulted in an almost instantaneous loss of colour.

## V - (a) The postulate of band-shifts in optically inactive camphanes; (b) the chloro-nitroso derivative of l-camphor oxime

The spectrum of Watson's d-(-)-2-chloro-2-nitroso-camphane (B.1), which had been subjected to irradiation with mercury-yellow light, was determined and rescaled to its original height. This revealed - not unexpectedly - a bodily displacement of the entire envelope to longer wavelengths (Hope, private communication). At this stage, then, four chloro-nitroso camphanes derived from d-camphor showed, to varying degrees, a change in their absorption spectra after irradiation. These were

1) d-(-)-2-chloro-2-nitrosocamphane (B.1).

2) d-2-chloro-2-nitroso-apocamphane-1-carboxylic acid (B.2, B.2').

3) d-(+)-2-chloro-2-nitroso-10-bromocamphane (B.3).

4) d-(+)-2-chloro-2-nitrosocamphane-10-sulphonic acid as pyridine salt (B.4).

It was now realised that absorption measurements alone could be used as a diagnostic test for the occurrence of a photo-process giving rise to products absorbing in the visible spectrum, and could be applied to optically inactive chloro-nitroso camphanes. This was conditioned, however, by the fact that the asymmetric centre at $C_1$ must direct the addition of chlorine in the same way in both enantiomorphic oximes to give true mirror-image

chloro-nitroso camphanes.

This postulate was substantiated by an examination of the optical properties of the chloro-nitroso derivative of l-camphoroxime (Clarke, Honours Thesis; Glasgow, 1953). l-Camphor, prepared by chromic anhydride oxidation of l-borneol, formed a highly crystalline oxime, chlorination of which in anhydrous ether gave a 2-chloro-2-nitrosocamphane. The general shape of the curve of rotatory dispersion showed it to be 1-(+)-2-chloro-2-nitrosocamphane, enantiomorphic with B.l. Irradiation of an ethanolic solution of this compound with mercury-yellow light resulted in an inversion of the Cotton effect with a corresponding bathochromic shift of the absorption spectrum. It could be safely assumed, therefore, that irradiation of an equimolecular mixture of d-(-) and l-(+)-2-chloro-2-nitrosocamphane would produce the expected shift in the spectrum. There still remained some fundamental difficulties in the application of this concept to inactive compounds, e.g., the relationship between the amount of shift and the composition of the mixture of isomers produced by irradiation. These are treated later in the Discussion.

## VI - 2-Chloro-2-nitroso-apocamphane-1-acetic acid (XXXI B.6) and its methyl ester (XXXIV B.7).

**'A'** - Attempts to prepare optically active 2-keto-apocamphane-1-acetic acid (XXIX) :

These experiments were undertaken before it became apparent that photoisomerisation was accompanied by a change in the absorption spectrum of both active and inactive compounds. All routes to the active acid proved abortive and thus will be discussed briefly.

(a) The protection of the ketonic group at $C_2$:-

All condensation reactions directed at replacing the 10-bromine atom would be complicated by the presence of the reactive methylene group at $C_3$ and the potentially enolizable carbonyl at $C_2$. Protection of this latter group with a suitable reagent would resolve these difficulties and it was decided to form the cyclic ethylene ketal of 10-bromocamphor by reacting the ketone with ethylene glycol in boiling benzene (catalysed by p-toluene sulphonic acid). The ketal (XVII) was obtained in excellent yield as a colourless, mobile oil which was stable to alkali. Hydrolysis to the ketone was easily effected with dilute methanolic sulphuric acid.

(b) The direct replacement of bromine with lithium:-

The carbonation of an organo-metallic compound

offered the easiest route to the corresponding acid.

The choice of metal was determined by the greater reactivity of organo-lithium compared with that of the more usual magnesium derivatives. The purified bromo-ketal in anhydrous ether under an atmosphere of nitrogen, failed to react with lithium, which had been finely divided and cut to give a clean surface.

(c) Coupling of the bromo-ketal with n-butyl lithium:-

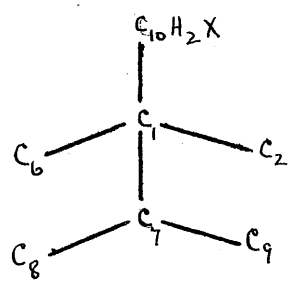
The ketal, dissolved in anhydrous ether, was gradually added to a dark grey solution of n-butyl lithium in ether. The reaction mixture was poured on to a large excess of dry carbon dioxide and extracted with caustic soda. The alkaline solution was acidified, extracted with ether and the ether extract dried. Removal of the ether gave a small amount of material (oil) which was hydrolysed with methanolic sulphuric acid. "Working-up" in the usual manner yielded a small amount of crystalline material whose melting point was about 70° higher than that for the inactive keto-acid. Almost 70% of the unchanged bromo-ketal was recovered from the original ethereal mother liquors (from caustic soda extraction of the carbonated material).

(d) Replacement of bromine by cyano:-

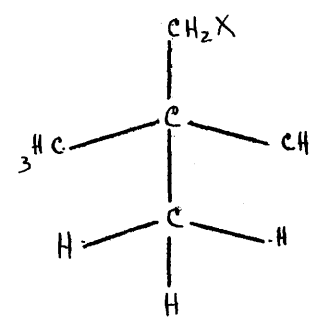
Replacement of bromine by cyano, followed by hydrolysis,

should give the required $\gamma$-keto acid. The prolonged heating of intimate mixtures of the bromo-ketone (or ketal), cuprous cyanide and pyridine (18 hours at 200°C) resulted in the formation of a dark brown mass, from which neither cyano compound nor starting material could be extracted.

The failure of all these reactions to yield a bromine-replaced camphor was not entirely surprising. An examination of the camphane skeleton revealed a close analogy with neopentyl compounds, which are notoriously inert to replacement reactions ($S_N2$) in anhydrous media. Neopentyl chloride, which had been heated at 200° for 90 hours with cuprous cyanide and pyridine, was recovered unchanged (65), while the Grignard reagent, slowly formed by neopentyl chloride, could only be characterised by reaction with phenylisocyanate to give tert.-butylacetanilide (66)




Camphane




Neopentyl

Moreover, it was found by Lowry that "there is no single reaction in which β-bromocamphor behaves as if it

contains the group "$-CH_2Br$" (67).

'B' - The synthesis of inactive 2-chloro-2-nitroso-apocamphane-1-acetic acid

The detection of the complexity of the photoprocess in chloro-nitroso camphanes by spectrophotometric measurements eliminated the necessity of using optically active compounds and made the synthesis of Hasselstrom's $\gamma$ - keto-acid more feasible. At several stages during this rather long and tedious preparation, the literature conditions were found to be inadequate and some time was spent in re-establishing these:-

(a) The yield of hydroxy-anilide ( XXVII) was doubled by strict limitation of the time of reaction and by careful "working-up". The reaction was stopped one-and-a-half hours after the addition of catalyst by pouring the ether into water. The phosphorus pentachloride, in which most of the anilide was occluded, was then carefully decomposed by adding it gradually to a mixture of ether and water. Repeated washing (total, 5 litres) of the combined ether extracts with water resulted in the deposition of appreciable amounts of crystalline product. The aqueous washings, after standing overnight, yielded almost 15% of the total amount. Yields of 60-65% were obtained without steam-distillation of the ether extract.

(b) The lactone (XXVIII) proved to be a light brown

solid which crystallised poorly from hexane (literature) and melted over a very wide range. It was finally purified by chromatography on silica gel and crystallisation from light petroleum (needles). Analysis confirmed that it was indeed the lactone of 2-hydroxy-apocamphane-1-acetic acid.

(c) Repeated attempts to prepare the keto-acid by boiling an alkaline solution of the lactone in the presence of solid potassium permanganate (literature) proved to be too drastic and no trace of the acid was obtained. The gradual addition of a solution of permanganate to an alkaline solution of the lactone at room temperature gave excellent yields of the acid which was characterised by analysis. The preparations of the oxime and its chloro-nitroso derivative presented no unusual difficulties and are described in the appropriate section.

2- Chloro-2-nitroso-apocamphane-1-acetic acid (XXXI B.6).

This compound, prepared in the usual way from the ether-soluble oxime, resembled its lower homologue B.2, B.2' in its chemical properties, viz. soluble in benzene but insoluble in petroleum ether at room temperature. It was purified by passage through a column of silica gel (benzene as solvent and eluent) and by crystallisation from a mixture of benzene and petroleum ether. The absorption spectrum of this material showed the

characteristic shoulder on the short-wave side of $\lambda$max. (630mμ), while the height of the band ($\varepsilon$max. = 17.7) was about 21% smaller than that for B.2 and thus indicated a marked weakening of the effect of the substituent on the electronic processes in the chromophore.

Irradiation with red light resulted in a rapid fall in $\log {}^{I_o}/_{I}$max. of about 25% (Table XIII) in 180 minutes. This was much faster than for the bromo-compound (B.3), but almost identical with that for the pyridine salt (B.4) which shows maximum absorption at the same wave-length. Examination of the spectrum after this time (Table XV, Graph XIII) revealed once more large increases (experimental) in $\log {}^{I_o}/_{I}$ on the long-wave side of $\lambda$max. All readings on the short-wave side were smaller than the initial values. Moreover, the position of $\lambda$max. had been displaced from 630mμ to 635mμ. It was concluded that the elimination of the chromophore at $C_2$ was preceded by a photo-process resulting in the formation of a compound also absorbing in the visible spectrum and which was thus responsible for the change in $\lambda$ max. etc. Polarimetric examination during irradiation showed no development of rotation, so that the two optical enantiomorphs must react photochemically at the same rate.

## TABLE XIII

Irradiation of 2-chloro-2-nitroso-apocamphane-1-acetic acid.

Concentration, c = 0.0471g./5ml. : 'oxygen-free'.

l = 0.0995dm. : t = 0.995cm.

Rotation (650mμ) - Absorption (630mμ)

Slits : Rotation - Entrance = 1.8 : Exit = 1.25

Absorption - 0.045mm.

| Mins. | α | $\log I_o/I$ | Temp. |
|---|---|---|---|
| 0 | 0.00 | 0.695 | 20.5 |
| 60 | 0.00 | 0.605 | 21.5 |
| 120 | 0.00 | 0.552 | 21.5 |
| 180 | 0.00 | 0.520 | 22.0 |

Note: The difference between $\log I_o/I_A$ at 630mμ. (Table XV) and $\log I_o/I$ at 630mμ (Mins. = 0) is consistent with photo-decomposition during a spectrum determination lasting one-and-a-half hours.

## TABLE XIV

Irradiation of 2-chloro-2-nitroso-apocamphane-1-methyl-acetate

Concentration, c = 0.0516g./5ml. : 'oxygen-free'

t = 0.995cm.

Absorption at 630mμ. Slit = 0.04mm.

| Mins. | $\log I_o/I$ | Temp. |
|---|---|---|
| 0 | 0.69 | 19 |
| 60 | 0.58 | 20 |
| 145 | 0.50 | 21 |

Note: The difference between $\log I_o/I_A$ at 630mμ (Table XVI) and $\log I_o/I$ at 630mμ. (Mins. = 0) is consistent with photo-decomposition during a spectrum determination lasting one-and-a-quarter hours.

## TABLE XV

### Absorption Spectrum of 2-chloro-2-nitroso-apocamphane-1-acetic acid before and after irradiation

Concentration, c =0.0471g./5ml. : 'oxygen-free'

l = 0.995cm. : Mol. Wt. = 235.71 : M = 0.03996

A = Before irradiation Slit at $\lambda$max. = 0.04mm.

B = After 180 minutes irradiation

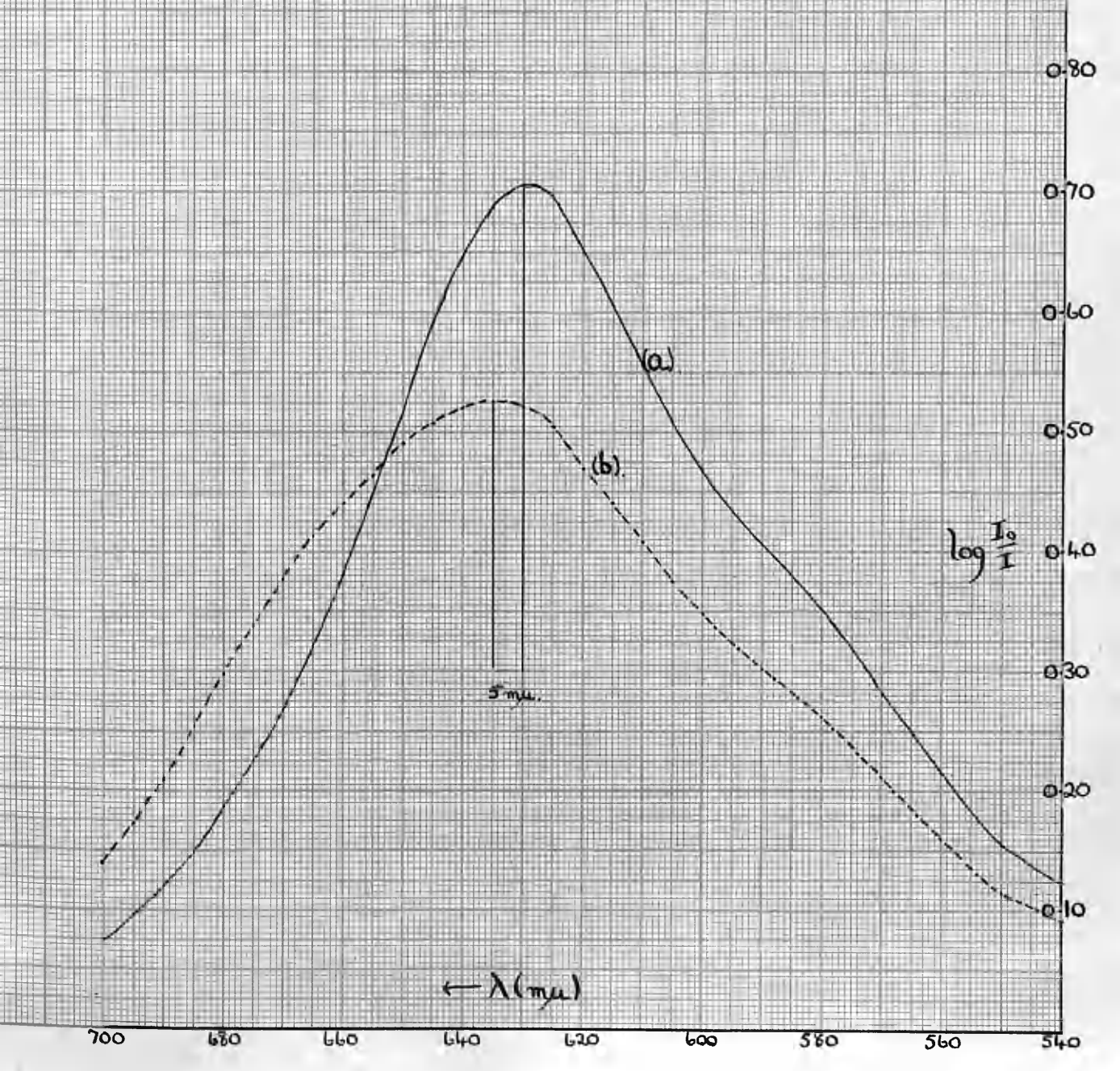
| $\lambda$(mμ) | $\varepsilon_A$ | $\log \frac{I_o}{I_A}$ | $\log \frac{I_o}{I_B}$ | $\lambda$(mμ) | $\varepsilon_A$ | $\log \frac{I_o}{I_A}$ | $\log \frac{I_o}{I_B}$ |
|---|---|---|---|---|---|---|---|
| 480 | 0.40 | 0.016 | 0.012 | 610 | 13.9 | 0.556 | 0.409 |
| 490 | 0.57 | 0.0225 | 0.017 | 615 | 15.2 | 0.605 | 0.440 |
| 500 | 0.82 | 0.0325 | 0.024 | 620 | 16.4 | 0.65 | 0.470 |
| 504 | 0.94 | 0.0375 | 0.028 | 625 | 17.5 | 0.695 | 0.505 |
| 510 | 1.16 | 0.046 | 0.034 | 630 | 17.7 | 0.705 | 0.520 |
| 514 | 1.32 | 0.0525 | 0.040 | 635 | 17.3 | 0.6875 | 0.525 |
| 520 | 1.66 | 0.066 | 0.049 | 640 | 16.3 | 0.6475 | 0.520 |
| 524 | 1.94 | 0.077 | 0.057 | 645 | 14.8 | 0.59 | 0.5075 |
| 530 | 2.34 | 0.093 | 0.069 | 650 | 12.9 | 0.515 | 0.490 |
| 534 | 2.67 | 0.106 | 0.078 | 655 | 11.3 | 0.4475 | 0.464 |
| 540 | 3.12 | 0.124 | 0.092 | 660 | 9.56 | 0.380 | 0.440 |
| 544 | 3.39 | 0.135 | 0.101 | 665 | 8.05 | 0.320 | 0.413 |
| 550 | 3.89 | 0.155 | 0.115 | 670 | 6.69 | 0.266 | 0.377 |
| 554 | 4.43 | 0.176? | 0.131 | 675 | 5.66 | 0.225? | 0.338 |
| 560 | 5.41 | 0.215 | 0.160 | 680 | 4.72 | 0.1875? | 0.298 |
| 564 | 6.09 | 0.242 | 0.180 | 685 | 3.71 | 0.1475? | 0.254 |
| 568 | 6.77 | 0.269 | 0.200 | 690 | 3.02 | 0.120 | 0.209 |
| 570 | 7.12 | 0.283 | 0.211 | 695 | 2.41 | 0.096 | 0.172 |
| 574 | 7.82 | 0.311 | 0.232 | 700 | 1.89 | 0.075 | 0.138 |
| 578 | 8.55 | 0.340 | 0.253 | 705 | 1.46 | 0.058 | 0.1175 |
| 580 | 8.85 | 0.352 | 0.262 | 710 | 1.21 | 0.048 | 0.100 |
| 584 | 9.41 | 0.374 | 0.278 | 715 | 0.94 | 0.0375 | 0.0825 |
| 588 | 9.96 | 0.396 | 0.295 | 720 | 0.75 | 0.030 | 0.069 |
| 590 | 10.2 | 0.405 | 0.302 | 725 | 0.63 | 0.025 | 0.0575 |
| 594 | 10.8 | 0.429 | 0.319 | 730 | 0.48 | 0.019 | 0.050 |
| 598 | 11.4 | 0.452 | 0.337 | 735 | - | - | 0.042 |
| 600 | 11.8 | 0.469 | 0.349 | 740 | - | - | 0.035 |
| 605 | 12.8 | 0.5075 | 0.375 | | | | |

Graph XIII.

Absorption spectrum of 2-chloro-2-nitroso-apocamphane-1-acetic acid (B.6).

(a) Before irradiation.

(b) After 180 mins.



Since such isomers are generally agreed to possess the same free energy, this was not a surprising result.

'C' - Inactive 2-chloro-2-nitroso-apocamphane-1-methylacetate (XXXIV B.7).

Substituent enlargement of the preceding 10-acid was undertaken to determine the effect, if any, of a sterically larger group on the extent of spectrum-displacement. The crude methyl ester (XXXII), prepared by the Fischer-Speier method, proved to be a mobile oil which was oximated as such in a buffered (potassium acetate) aqueous solution of hydroxylamine hydrochloride. The oxime (XXXIII), initially obtained as an oil, was induced to solidify by scratching small amounts on a watch glass and then by seeding the bulk (m.p. 61-66°C). No attempt was made to purify it by crystallisation. Removal of the ether after chlorination of XXXIII at 0°C. gave a small amount of deep blue viscous oil. This was chromatographed through a column of silica gel with benzene as solvent and eluent. Vacuum distillation of the solvent yielded the blue ester as a sticky solid, which was dried by pressing on porous plate. It was extremely soluble in most organic solvents at room

temperature, and an analytical specimen was prepared by further chromatography followed by complete removal of the solvent (m.p. 55-58°C).

Irradiation with red light under conditions identical with those used for all the preceding compounds resulted in a fall of $\log I_o/I$ at $\lambda$ max. (630mμ) of about 27% in 145 minutes (Table XIV). This was slightly faster than for the 10-acid (XXXI). The photoisomerisation of this material was revealed by the examination of the absorption spectrum after 145 minutes of irradiation (Table XVI, Graph XIV). The observed values of $\log I_o/I$ on the long- and short-wave sides of $\lambda$ max. were respectively greater and smaller than the initial values. The position of $\lambda$ max. was displaced to the red by about 10mμ, i.e. from 630 to 640mμ. It was concluded from these results that the introduction of a methyl group in XXXI had in no way eliminated the photoisomerisation.

VII - 2-Chloro-2-nitroso-10-benzylcamphane (XXXIX B.8).

The starting material for the $\gamma$-keto acid (XXIX), namely 10-benzoyl borneol (XXV), offered an attractive route to an inactive, 10-substituted camphor with all the properties necessary for the successful investigation of photomutarotation. 10-Benzyl camphor (XXVII), with its sterically large and chemically inert substituent,

## TABLE XVI

Absorption Spectrum of 2-chloro-2-nitroso-apocamphane-1-methylacetate before and after irradiation

Concentration, c = 0.0516g./5ml. : 'oxygen-free'

l = 0.995cm. Mol. Wt. = 259.73

M = 0.03973

A = Before irradiation Slit at $\lambda$ max. = 0.041mm.

B = After 145 minutes irradiation

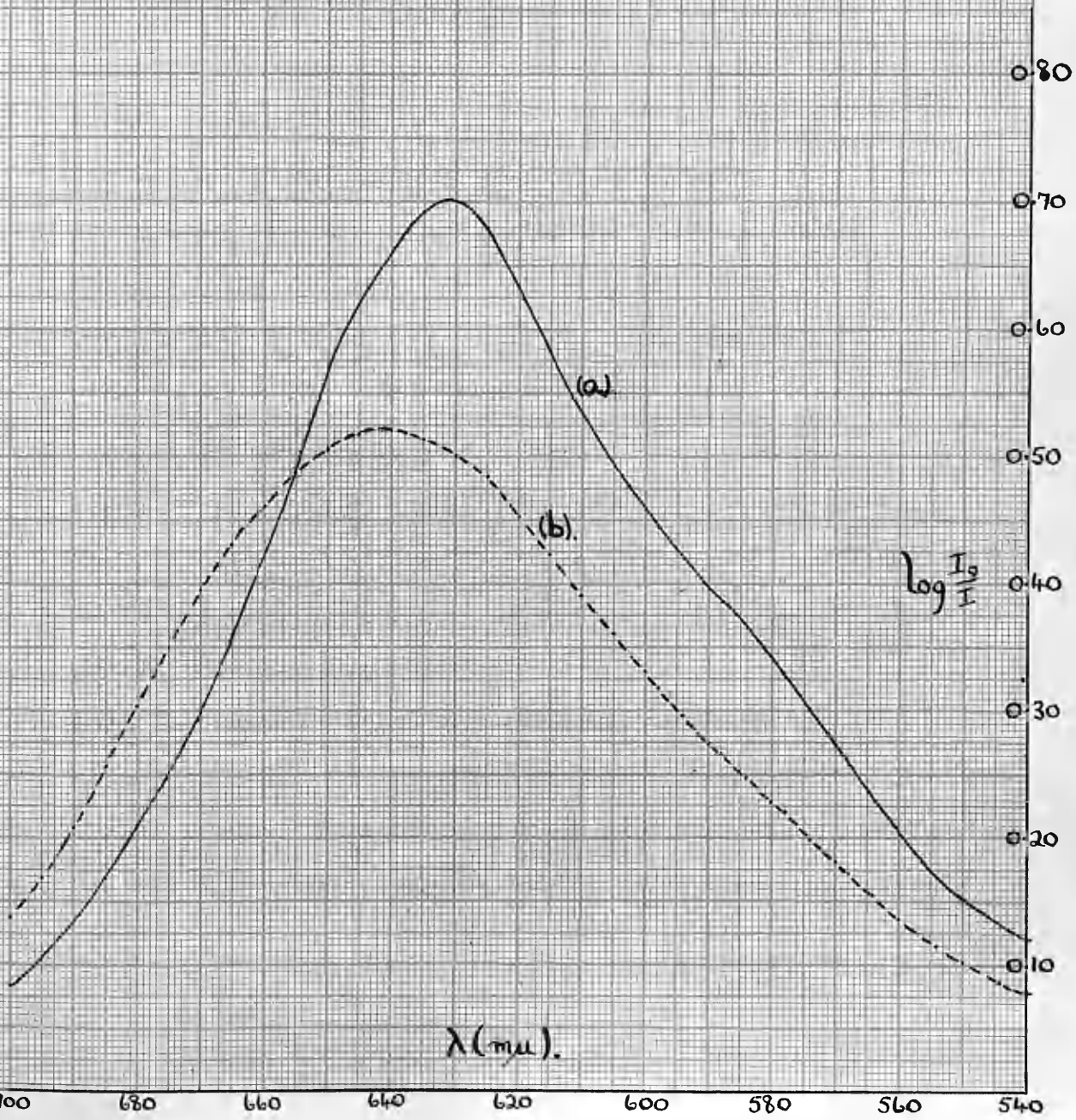
| $\lambda$ (mμ) | $\varepsilon_A$ | $\log \frac{I_o}{I_A}$ | $\log \frac{I_o}{I_B}$ | $\lambda$ (mμ) | $\varepsilon_A$ | $\log \frac{I_o}{I_A}$ | $\log \frac{I_o}{I_B}$ |
|---|---|---|---|---|---|---|---|
| 480 | 0.39 | 0.0155 | 0.010 | 610 | 13.5 | 0.535 | 0.390 |
| 490 | 0.58 | 0.023 | 0.015 | 615 | 14.7 | 0.5825 | 0.423 |
| 500 | 0.82 | 0.0325 | 0.021 | 620 | 16.1 | 0.635 | 0.452 |
| 504 | 0.94 | 0.037 | 0.023 | 625 | 17.2 | 0.680 | 0.484 |
| 510 | 1.14 | 0.045 | 0.030 | 630 | 17.7 | 0.70 | 0.500 |
| 514 | 1.32 | 0.052 | 0.034 | 635 | 17.5 | 0.69 | 0.513 |
| 520 | 1.65 | 0.065 | 0.043 | 640 | 16.7 | 0.660 | 0.520 |
| 524 | 1.89 | 0.075 | 0.0475 | 645 | 15.7 | 0.620 | 0.5175 |
| 530 | 2.30 | 0.091 | 0.057 | 650 | 14.4 | 0.57 | 0.505 |
| 534 | 2.59 | 0.1025 | 0.065 | 655 | 12.4 | 0.488 | 0.488 |
| 540 | 3.04 | 0.120 | 0.078 | 660 | 10.6 | 0.420 | 0.460 |
| 544 | 3.31 | 0.131 | 0.0875 | 665 | 9.11 | 0.360 | 0.430 |
| 550 | 3.79 | 0.150 | 0.103 | 670 | 7.54 | 0.298 | 0.395 |
| 554 | 4.28 | 0.169 | 0.115 | 675 | 6.38 | 0.252 | 0.350 |
| 560 | 5.11 | 0.202 | 0.136? | 680 | 5.31 | 0.210 | 0.304 |
| 564 | 5.79 | 0.229 | 0.155 | 685 | 4.28 | 0.169 | 0.256? |
| 568 | 6.50 | 0.257 | 0.1725? | 690 | 3.40 | 0.1345 | 0.208 |
| 570 | 6.86 | 0.271 | 0.182? | 695 | 2.64 | 0.1045 | 0.168 |
| 574 | 7.56 | 0.299 | 0.199 | 700 | 2.14 | 0.0845 | 0.1375 |
| 578 | 8.28 | 0.3275 | 0.220 | 705 | 1.64 | 0.065 | 0.115 |
| 580 | 8.66 | 0.3425 | 0.2275 | 710 | 1.33 | 0.0525 | 0.094 |
| 584 | 9.23 | 0.365 | 0.2475 | 715 | 1.06 | 0.042 | 0.080 |
| 588 | 9.74 | 0.385 | 0.366 | 720 | 0.78 | 0.031 | 0.065 |
| 590 | 9.99 | 0.395 | 0.274 | 725 | 0.66 | 0.026 | 0.054 |
| 594 | 10.6 | 0.420 | 0.296 | 730 | 0.56 | 0.022 | 0.0475 |
| 598 | 11.2 | 0.444 | 0.317 | 735 | 0.43 | 0.017 | 0.039 |
| 600 | 11.6 | 0.4575 | 0.330 | 740 | 0.38 | 0.015 | 0.032 |
| 605 | 12.5 | 0.494 | 0.360 | | | | |

# Graph XIV.

## Absorption spectrum of 2-chloro-2-nitroso-apocamphane-1-methylacetate (B.7).

(a) Before irradiation.

(b) After 145 mins.



could be prepared from the keto-alcohol (XXV) by (a) specific reduction of carbonyl to methylene and (b) oxidation of a secondary alcohol group to the corresponding ketone. Both these steps were successfully carried out and are discussed briefly below.

(a) Direct use of the Huang-Minlon reduction (68) of carbonyl to methylene (XXV→XXXVI) by thermal decomposition of the intermediate hydrazone (XXXV) in alkaline diethylene glycol proved unsuccessful because of the low solubility of XXXV in this medium. Inexplicably, however, the isolated and purified hydrazone dissolved readily in the glycol by heating to a temperature not exceeding 100°C. Nitrogen was readily split out by heating at 180-200°C. for a short time in an open flask, and gave the secondary alcohol (XXXVI) in good yield. The latter was purified by distillation but could not be induced to crystallise. It was characterised by its phenylurethane, m.p. 139-140°C.

(b) The above alcohol was smoothly converted to the ketone (XXXVII) by chromic anhydride oxidation in glacial acetic acid. This product also proved to be a viscous oil which failed to crystallise. Its oxime, prepared

in pyridine (64), was a stable solid which crystallised readily from petroleum ether in fine, matted needles (m.p. 127-127.5°C). Its identity was confirmed by analysis.

Chlorination of the ether-soluble oxime (which did not form an oxime hydrochloride) to give the blue chloro-nitroso derivative was remarkably slow. Dissolution in light petroleum of the pale blue material (obtained by removal of the ether) resulted in the precipitation of appreciable amounts of unreacted starting material (mixed melting point). This was removed by filtration and the solution was then passed through a column of activated alumina. Removal of the solvent under vacuum yielded a small amount of blue gum which did not crystallise from the usual solvents. No attempt was made to submit it for analysis and it was used in this state for the irradiation experiments.

The photochemical decomposition of this material proceeded very slowly, taking 300 minutes to decompose by about 20% (Table XVII). In this it was comparable to the 10-bromo compound but much slower than the 10-acid and its methyl ester. Determination of its spectrum after 300 minutes and 540 minutes (corresponding to 33% ca. decomposition) showed neither a displacement

## TABLE XVII

Irradiation of 2-chloro-2-nitroso-10-benzylcamphane

Concentration, c = unknown : 'oxygen-free'

t = 0.0995cm.

Absorption at 665mμ. Slit = 0.035mm.

| Mins. | $\log \frac{I_o}{I}$ | Temp. |
|---|---|---|
| 0 | 1.017 | 19 |
| 60 | 0.93 | 20.5 |
| 150 | 0.860 | 21.5 |
| 240 | 0.825 | 22 |
| 300 | 0.805 | 22 |
| Left overnight | | |
| 540 | 0.69 | 22 |

Note: Difference in $\log I_o/I_A$ at 665mμ (Table XVIII) and $\log I_o/I$ at 665mμ (Mins. = 0) is consistent with photodecomposition during a spectrum determination lasting one-and-a-half hours.

of $\lambda$max. nor increases in $\log I_o/I$ (Table XVIII, Graph XV). However, several points of interest were revealed by a comparison of the original spectrum with those obtained after irradiation but rescaled to the initial height ($\log \frac{I_o}{I} = 1.025$). The percentage differences were negative on the short-wave side of $\lambda$ max. (average difference = 1.5%), while on the long-wave side they were positive (average difference = 3%). Admittedly, these were not very different from the permitted experimental error of 2%, but the absence of a random distribution of error in these measurements indicated that elimination of the active centre at $C_2$ did not take place directly. Moreover, the almost exact superposition of the re-scaled values, after 300 and 540 minutes of irradiation, showed that the maximum amount of isomerisation had taken place within the first 300 minutes. Although the balance of evidence tended to confirm that a secondary photo-process had taken place, it must be emphasised that a non-displacement of the spectrum of an inactive compound cannot be interpreted unambiguously and that the results for this compound must be considered with caution.

## TABLE XVIII

Absorption Spectrum of 2-chloro-2-nitroso-10-benzyl-camphane before and after irradiation

Concentration, c = unknown : 'oxygen-free'

l = 0.995cm. : Mol. Wt. = 291.82.

A = Before irradiation

B = After 300 minutes Slit at $\lambda$ max. = 0.035mm.

C = After 540 minutes

| $\lambda(m\mu)$ | $\log \frac{I_o}{I_A}$ (1) | $\log \frac{I_o}{I_B}$ (2) | $\log \frac{I_o}{I_C}$ (3) | $\log \frac{I_o}{I_B}$ x 1.273 (4) | $\log \frac{I_o}{I_C}$ x 1.486 (5) | % $\Delta$ (4)-(1) |
|---|---|---|---|---|---|---|
| 500 | 0.0275 | | | | | |
| 504 | 0.032 | | | | | |
| 510 | 0.036 | | | | | |
| 514 | 0.041 | | | | | |
| 520 | 0.051? | | | | | |
| 524 | ? | | | | | |
| 530 | 0.0645 | 0.048 | 0.041 | 0.061 | 0.061 | |
| 534 | 0.0725 | 0.053 | 0.047 | 0.067 | 0.069 | |
| 540 | 0.090 | 0.067 | 0.056 | 0.085 | 0.083 | |
| 544 | 0.102 | 0.075 | 0.0645 | 0.095 | 0.096 | |
| 550 | 0.122 | 0.0935 | 0.079 | 0.119 | 0.117 | -2.5 |
| 554 | 0.1375 | 0.105 | 0.092? | 0.134 | 0.137 | -2.5 |
| 560 | 0.162 | 0.1245 | 0.106 | 0.158 | 0.158 | -2.5 |
| 564 | 0.176 | 0.135 | 0.115 | 0.172 | 0.171 | -2.3 |
| 570 | 0.198 | 0.1525 | 0.1295 | 0.194 | 0.192 | -2.0 |
| 574 | 0.215 | 0.165 | 0.140 | 0.211 | 0.208 | -1.9 |
| 578 | 0.236 | 0.181 | 0.153 | 0.230 | 0.227 | -2.5 |
| 580 | 0.248 | 0.191 | 0.162 | 0.243 | 0.241 | -2.0 |
| 584 | 0.278 | 0.213 | 0.185? | 0.271 | 0.275 | -2.5 |
| 588 | 0.310 | 0.240 | 0.204 | 0.306 | 0.303 | -2.3 |
| 590 | 0.330 | 0.255 | 0.218? | 0.325 | 0.324 | -1.5 |
| 594 | 0.370 | 0.285 | 0.244 | 0.363 | 0.363 | -1.9 |
| 598 | 0.416 | 0.3185 | 0.2725 | 0.405 | 0.405 | -2.6 |
| 600 | 0.4375 | 0.340 | 0.287 | 0.433 | 0.426 | -1.0 |
| 605 | 0.484 | 0.374 | 0.320 | 0.476 | 0.476 | -1.7 |
| 610 | 0.522 | 0.409 | 0.347 | 0.521 | 0.516 | -0.2 |
| 615 | 0.555 | 0.433 | 0.368 | 0.551 | 0.547 | -0.7 |
| 620 | 0.588 | 0.458 | 0.390 | 0.583 | 0.579 | -0.9 |
| 625 | 0.625 | 0.487 | 0.412 | 0.619 | 0.612 | -0.9 |
| 630 | 0.655 | 0.51 | 0.435 | 0.649 | 0.646 | -0.9 |

over.

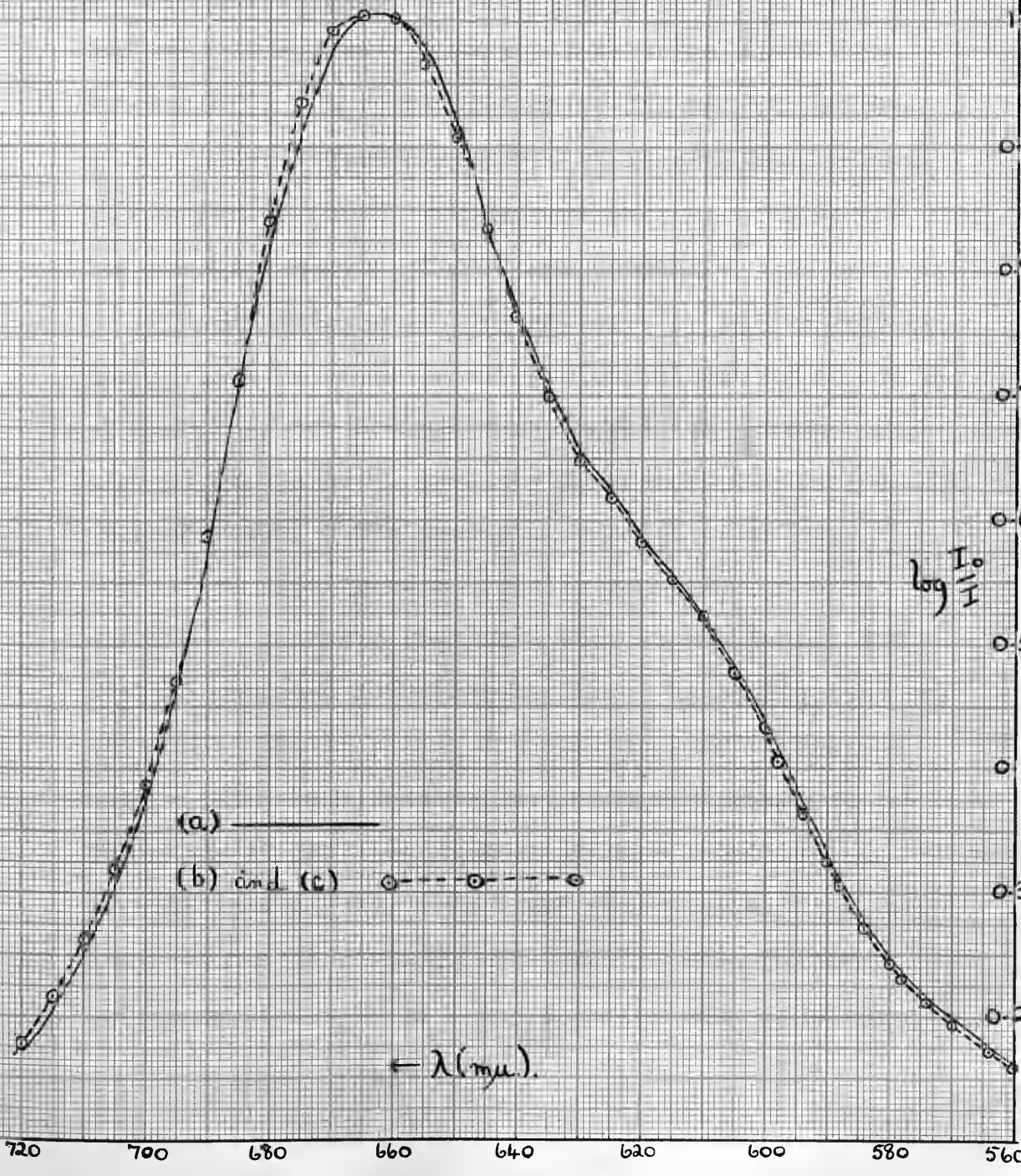
## TABLE XVIII
(cont.)

| $\lambda$ (mμ) | $\log \frac{I_o}{I_A}$ (1) | $\log \frac{I_o}{I_B}$ (2) | $\log \frac{I_o}{I_c}$ (3) | $\log \frac{I_o}{I_B}$ x 1.273 (4) | $\log \frac{I_o}{I_c}$ x 1.486 (5) | % Δ (4)-(1) |
|---|---|---|---|---|---|---|
| 635 | 0.705 | 0.55 | 0.469 | 0.70 | 0.697 | -0.7 |
| 640 | 0.768 | 0.600 | 0.51 | 0.764 | 0.758 | -0.5 |
| 645 | 0.832 | 0.655 | 0.555 | 0.834 | 0.825 | +0.2 |
| 650 | 0.923 | 0.712 | 0.608 | 0.906 | 0.903 | -1.8 |
| 655 | 0.975 | 0.758 | 0.648 | 0.965 | 0.963 | -1.0 |
| 660 | 1.015 | 0.798 | 0.680 | 1.015 | 1.01 | -0.1 |
| 665 | 1.025 | 0.805 | 0.690 | 1.025 | 1.025 | - |
| 670 | 0.975 | 0.779 | 0.668 | 0.992 | 0.993 | +1.7 |
| 675 | 0.908 | 0.734 | 0.628 | 0.934 | 0.933 | +2.9 |
| 680 | 0.824 | 0.660 | 0.565 | 0.840 | 0.839 | +1.9 |
| 685 | 0.704 | 0.560 | 0.484 | 0.713 | 0.719 | +1.3 |
| 690 | 0.562 | 0.460 | 0.391 | 0.586 | 0.581 | +4.3 |
| 695 | 0.460 | 0.370 | 0.324 | 0.471 | 0.481 | +2.4 |
| 700 | 0.371 | 0.304 | 0.2595 | 0.387 | 0.386 | +4.3 |
| 705 | 0.305 | 0.251 | 0.2175? | 0.319 | 0.323 | +4.6 |
| 710 | 0.249 | 0.207 | 0.1775 | 0.264 | 0.264 | +5.2 |
| 715 | 0.204 | 0.170 | 0.1455 | 0.216 | 0.216 | +5.9 |
| 720 | 0.1725 | 0.138 | 0.118 | 0.176 | 0.175 | +2.0 |
| 725 | 0.140 | 0.116 | 0.099 | 0.148 | 0.147 | +5.7 |
| 730 | 0.118 | 0.098 | 0.0845 | 0.125 | 0.126 | +5.9 |
| 735 | 0.100 | 0.080 | 0.068 | 0.102 | 0.101 | +2.0 |
| 740 | 0.083 | 0.067 | 0.0577 | 0.085 | 0.086 | +2.4 |
| 745 | 0.071 | 0.0545 | 0.046 | 0.069 | 0.068 | -2.8 |
| 750 | 0.0565 | 0.045 | 0.039? | 0.057 | 0.058 | |

# Graph XV.

## Absorption spectrum of 2-chloro-2-nitroso-10-benzylcamphane (B.8).

(a) Before irradiation. (b) After 300 mins. (rescaled) (c) After 540 mins. (rescaled).



## VIII - Attempts to prepare optically active 2-chloro-2-nitroso-10-hydroxycamphane (XXIII, B.9) and some ether derivatives of the hydroxy-ketone (XXI)

The replacement of bromine by hydroxy in 10-bromocamphor, which was achieved by Iki (69), represents the only exception to Lowry's conclusion about this ketone (67). The preparation of XXI and its chloro-nitroso derivative was undertaken because the hydroxy substituent offered a further variation, both in the size and chemical nature of a 10-substituent.

The drastic conditions employed by Iki to replace the 10-bromine atom, namely prolonged heating at 190°C of a melt of the bromo-ketone, potassium acetate and glacial acetic acid, gave the 10-acetoxy derivative (XX) in good yield. The product, reported as an oil, solidified after vacuum distillation and melted at 28-29°C. Analysis confirmed that it was indeed the acetoxy compound described by Iki. Saponification of XX with alcoholic potash yielded the crude hydroxy-ketone (XXI) as a pale yellow, rather sticky, solid. The oxime of XXI, prepared in aqueous caustic soda, crystallised readily from light petroleum as fine, non-lustrous needle clusters which melted at 178-179°C., softening at 90-100°C. Its identity was established

by micro-analysis. Prolonged chlorination of XXII in ether gave, at best, a pale green colour. The extremely pale blue, wax-like solid obtained by the removal of the ether, appeared to be contaminated with starting material from which it could not be separated. Change of reaction medium to pyridine and dilute hydrochloric acid, also failed to give a pure product. Attempts to prepare the chloro-nitroso derivative (XXIII) from the oxime hydrochloride were unsuccessful. Passage of dry hydrochloric acid into a concentrated solution of the oxime in ether resulted in the instantaneous precipitation of a low melting (20-30°C), hygroscopic solid, presumably the hydrochloride.

The preparation of ethers from XXI by the usual Williamson method must be preceded by the blocking of the carbonyl function at $C_2$. As with the 10-bromo-ketone, this would eliminate condensation at the reactive methylene group on $C_3$ and at the potentially enolisable ketonic group. Accordingly, attempts were made to prepare the cyclic ethylene ketal of XXI by reacting it with ethylene glycol in boiling benzene. Removal of the solvent after a total reflux time of about 50 hours, followed by high-vacuum distillation of the residue, gave a small amount of water-insoluble oil. The residue,

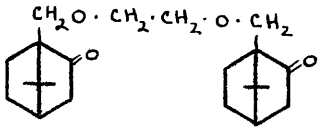
solidified on cooling, and failed to crystallise. It could be only partly purified by vacuum sublimation. Analysis of this material, which closely resembled camphor in appearance, gave the following figures:-

%C , 69.84 : %H , 9.26

The calculated values for a molecule doubly-condensed through the hydroxy-group (below) are:-

%C , 70.98 : %H , 10.13

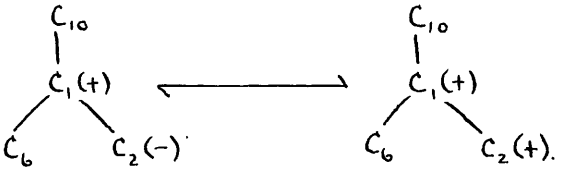
in reasonable agreement with




the experimental values. In this respect, the hydroxy-ketone (XXI) resembles the 1:2-hydroxy-ketones described by Ewlampiew (70, 71), which do not form ketals but lactolides. The syntheses of 10-ethers had therefore to be abandoned.

## DISCUSSION

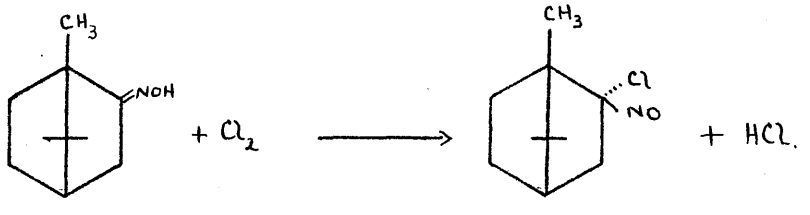
The investigation of the optical properties of 2-chloro-2-nitrosocamphanes is complicated by the presence of the adjacent asymmetric centre at $C_1$ which stereo-directs the addition of chlorine to $C_2$. The effect of $C_1$ is essentially composite, representing the contribution of the centres at both $C_1$ and $C_4$. The effect and configuration of the latter is, of necessity, fixed by the $C_1$-$C_4$ bridge. If stereo-selective addition occurs as an irreversible process there is, in consequence, a preferential formation of one of the two possible diastereoisomers. Again, if either of the two asymmetric centres is optically labile (say $C_2$), the composition of the equilibrium mixture can be controlled by first-order asymmetric transformation, examples of which have been studied by Turner and Harris (72).




The application of such a concept to chloro-nitroso camphanes is not without justification. The complicated Cotton effect shown by 2-chloro-2-nitroso-apocamphane-1-carboxylic acid (B.2), when prepared from the oxime or oxime hydrochloride in ether, represents without doubt a mixture

of both diastereo-isomerides present in large amounts. The gradual simplification of the curve of rotatory dispersion observed when the mixture is dissolved in ethanol (Graph I) can be interpreted in terms of an asymmetric transformation to give a mixture with a preponderance of the (+) form, which has greater stability (lowest free energy) in the solvent used. One other type of equilibrium-displacement has been observed with the chloro-nitroso camphanes. Preparation of the parent compound (-)-2-chloro-2-nitroso-camphane (B.1) from the oxime hydrochloride in ether, instead of from the oxime, results in the formation of a mixture greatly enriched in the (-) form (50). Of the optically active $C_1$, $C_{10}$ substituted camphor oximes described in the previous section, two do not form oxime hydrochlorides (viz., XV and III), while chlorination of the oxime hydrochloride of 2-keto-apocamphane-1-carboxylic acid (VII) gives a product whose complicated Cotton effect is so little different from that from the oxime that no pertinent deductions can be made. The effect of hydrochloride formation on the equilibrium mixture has not been satisfactorily explained. It may well be that it operates by yielding only one of the two theoretically possible stereoisomeric oximes (which have never been detected) and thus predetermines the position of the

carbon-nitrogen bond. There exists, in this, a close analogy with the transformation of β-benzilmonoxime into the more stable α-form under the catalytic influence of undissociated hydrogen chloride, lithium chloride or tetramethylammonium chloride. This was investigated by Taylor and Roberts (51), who attributed the change to a reduction in the tortional rigidity of the carbon-nitrogen double bond by interaction with the fields of the undissociated catalysts. It is difficult to reconcile this mechanism with the fact that chlorination of the oxime to give a small excess of the (-) form is carried out in the presence of large concentrations of undissociated hydrochloric acid.




The mutarotations of organic molecules (e.g., α and β-d-glucose and 3-nitrocamphor) are almost invariably observed in the visible region of the spectrum, where no absorption band is present. The curves of rotatory dispersion for such molecules are consequently quite simple and devoid of structure. It is therefore conceivable that the changes in rotation are due to the formation of molecules of intermediate structure also absorbing outwith this range and with simple dispersion

curves. All chloro-nitroso camphanes, however, absorb in the region 500-750mμ. and show an anomalous curve of rotatory dispersion. Photomutarotation to give an inverted Cotton effect in the same wavelength range therefore indicates the maintenance of a monomeric nitroso unit in the camphane molecule, and available evidence supports the assumption that mutarotation involves an inversion of configuration about $C_2$. This concept is not foreign to the field of substituted camphors. The classical mutarotation of 3-nitro-camphor - at one time attributed to the formation of the pseudo-nitro compound (73) - has been shown by R. P. Bell, on chemical evidence, to be an inversion of the configurations about $C_3$ to give the diastereoisomer (74).

The evaluation of the effects of substitution by polarimetric measurements is based on the following assumptions:-

(a) Substitution at $C_1$ and $C_{10}$ does not alter their spatial configurations (see section on 'Substituted chloro-nitroso camphanes').

(b) The contribution of these centres to the total rotation in the visible spectrum is very much smaller than that of the nitroso group.

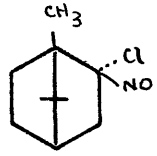
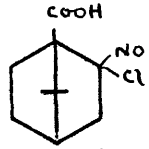
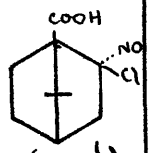
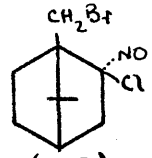
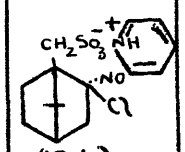
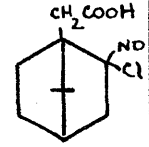
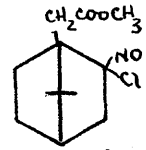
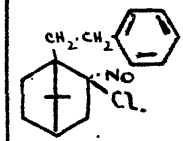
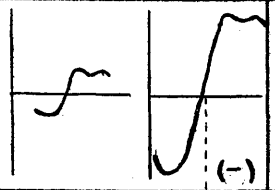
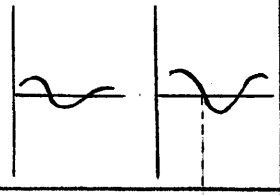
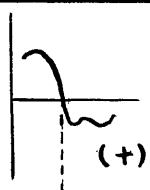
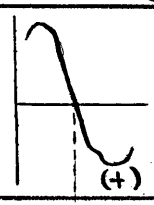
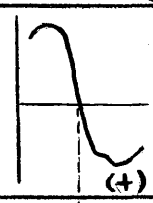
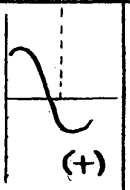
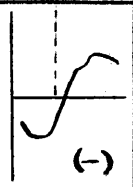
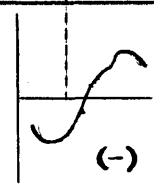
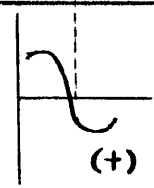
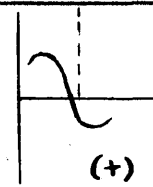
It is argued, therefore, that changes in the sign of the curves of rotatory dispersion are intimately related

to changes in the configurations about $C_2$. That is, chloro-nitroso camphanes with Cotton effects of opposite sign have different configurations at $C_2$.

The results obtained for the series of substituted camphanes or apocamphanes are summarised in the accompanying chart and are discussed below.

(a) Effect of substitution on the curves of rotatory dispersion:

If it is accepted that chlorination of the oxime or oxime hydrochloride yields a preponderance of the diastereoisomer of lowest free energy, then it becomes obvious that, in the compounds investigated, a fundamental function of the substituent is to alter the thermodynamic stability of the molecule. This is borne out by B.3 and B.4 the Cotton effects of which are opposite to that for the parent camphane (B.1) and indicate different configurations about $C_2$. This change in the $C_2$-configurations by the introduction of a substituent can be accounted for in two ways. The substituent may operate by mechanically determining the position of entry of the chlorine atom and may thus be said to exert a steric effect (applicable to B.3 and B.4), or it may operate by affecting the stereo-directing properties of the asymmetric centre at $C_1$.

| |  (B.1) |  (B.2) |  (B.2') |  (B.3) |  (B.4) |  (B.6) |  (B.7) |  (B.8). |
|---|---|---|---|---|---|---|---|---|
| OXIME or OXIME HYDROCHLORIDE | Oxime Oxime Hyd. | Oxime Oxime Hyd. | Oxime | Oxime | Oxime | Oxime | Oxime | Oxime. |
| SOLVENT. | ETHER ETHER | ETHER ETHER | PYRIDINE | ETHER | PYRIDINE | ETHER | ETHER | ETHER. |
| DARK REACTION. | | +ve. | | | | | | |
| COTTON EFFECT. unirradiated. |  (−) |  |  (+) |  (+) |  (+) | | | |
| COTTON EFFECT. irradiated. |  (+) |  (−) |  (−) |  (+) |  (+) | | | |
| SPECTRUM DISPLACEMENT. | RED | | BLUE | RED | RED | RED | RED | ?? |
| ABSORPTION. $\lambda_{max.}$ unirradiated (mμ) | 660 | 640 | 640 | 650 | 630 | 630 | 630 | 665 |
| ABSORPTION. $\lambda_{max.}$ irradiated (mμ). | 665 | | 635 | 660 | 635 | 635 | 640 | ZERO. |
| ROTATION CURVE DISPLACEMENT. | RED | BLUE | BLUE | RED | RED | | | |
| EXPERIMENTAL INCREASE in $\log I_0/I$. | No | | No | YES | YES | YES | YES | No. |

The mixture of isomers obtained by chlorination of the oxime or oxime hydrochloride of 2-keto-apocamphane-1-carboxylic acid in ether would suggest a marked 'loosening' of the directing power of $C_1$. That the (+) form of B.2 is the most stable can be deduced by the 'dark-reaction' exhibited by the mixture. On the other hand, the formation of the (+) isomer in pyridine can be attributed to the influence of the solvent in determining the isomer with lower free energy. The evidence suggests that substitution, resulting in the replacement or modification of the 10-methyl group, favours a configuration at $C_2$ opposite to that in B.1 and it is predicted that the Cotton effects of the inactive camphanes B.6, B.7 and B.8 would be similar to those of the 10-bromo and pyridine salt. In the absence of an established structure for any one of the active compounds, it is impossible at this stage to assign even relative configurations to the members of the series. At best, it can be said that the configuration at $C_2$ in B.1 is opposite to that in B.2', B.3 and B.4.

(b) Effect of substitution on the absorption process located in the nitroso group:

That the substituent exerts some influence on the height of the excited level above the ground level of the

absorption process is shown by an examination of the position of maximum absorption ( $\lambda$ max.) for the series. The difference in $\lambda$ max. for the 10-benzyl and parent camphanes, namely 35mμ, represents a difference in the energies of the excited levels of some 2,400cals./mole. If the two possible diastereoisomers have different spectra, then the composition of the mixture will also determine the position of $\lambda$ max.

It is clear from (a) and (b) above that the effect of a substituent is multiple, influencing both the thermodynamic and photochemical properties of the molecule and that the assessment of the over-all effect of substitution must be based on a consideration of these two influences.

(c) Effect of substitution on photomutarotation:

The rapid rates of inversion of the curves of rotatory dispersion of (-)-2-chloro-2-nitrosocamphane (B.1) and 2-chloro-2-nitroso-apocamphane-1-carboxylic acid (B.2,2') by irradiation with red light is assumed to be an inversion of the configuration about $C_2$. As stated on page 68, this concept is not new in the field of substituted camphors. The mutarotation of B.1 has been partly substantiated by Mitchell and Hope (75) who isolated, after irradiation, a blue product with an

inverted Cotton effect and which proved on analysis to be isomeric with the starting material. This result, however, cannot be interpreted unambiguously and will be discussed later. The most interesting result obtained from the irradiation of B.1 and B.2,2' is perhaps the observation of a simultaneous displacement of the curves of rotatory dispersion and absorption. It is emphasised at this point that, in both cases, although the shift of $\lambda$ max. was detected, no experimental increases in $\log {}^{I_o}/_{I}$ were observed during the course of irradiation. This proved to be of considerable importance later, when attempts were made to assess the effect of irradiation on the 10-bromo and 10-pyridine salt camphanes (i.e. B.3 and B.4).

Since the product of a 2:2'-mutarotation would be a diastereoisomer with different molecular constants, the displacement of the rotatory dispersion and absorption curves was taken at first sight to support the postulate of simple inversion of configuration about $C_2$. On this basis, attempts were made to use spectrophotometric measurements as a criterion by which to assess the effect of substitution on the photomutarotation of substituted chloro-nitroso camphanes. Moreover, the

detection of a band-shift with l-(+)-2-chloro-2-nitroso camphane suggested the possibility of applying this test to optically inactive compounds, and thus the syntheses of 2-chloro-2-nitroso-apocamphane-1-acetic acid, its methyl ester and 2-chloro-2-nitroso-10-benzylcamphane were undertaken. It was early recognised, however, that the use of band-shifts as a diagnostic test for simple inversion was not without certain difficulties which are outlined below.

Irradiation of a chloro-nitroso camphane can change the spectrum in two distinct ways:-

(i) By a change in the medium; e.g. increase in acidity by hydrochloric acid formed by photolysis. The nitroso absorption process has been defined as an $n \rightarrow \pi^*$ transition (38), which, according to Kasha (76), changes or disappears in acidic media. Again, McConnell (77) has classified $n \rightarrow \pi^*$ transitions by a blue-shift shown by increase in the polarity of the solvent.

(ii) By the formation of a non-isomeric chloro-nitroso compound; e.g. the removal of a salt group, as in B.4 or an ester group, as in B.7 by hydrochloric acid produced by photolysis.

The tendency for the shifts observed with the chloro-nitroso camphanes to be bathochromic (5 to 1) and the fact that hydrochloric acid present in concentration greater than that produced by total photolysis has no

effect on the spectrum of B.4 (Table XII) indicate that mechanisms (i) and (ii) are not operative.

The combined spectrophotometric results (chart) illustrate that all the compounds investigated change their absorption spectra on irradiation. These include the optically inactive 2-chloro-2-nitroso-10-benzyl-camphane (B.8) whose spectrum, determined after 300 minutes and rescaled to its original height, shows variations in $\log I_o/I$ from the initial values, which are all greater on the long-wave side of $\lambda$max. (3%) and smaller on the short-wave side (1.5%). The absence of a random variation in $\log I_o/I$ strongly supports the conclusion that a change in the spectrum has taken place. It therefore appears that mutarotation, which is associated with band-shift in both B.1 and B.2,2', occurs in all the substituted chloro-nitroso camphanes.

The polarimetric and absorption measurements, however, cannot be reconciled easily and so this postulate of the generality of 2:2'-mutarotation in substituted chloro-nitroso camphanes is debatable. The outstanding discrepancies between these two methods of investigation are enumerated below.

1) In those cases where rotatory dispersion curves are inverted by irradiation (viz. B.1 and B.2'), the

bodily displacement of the absorption band is not detectable until the spectrum obtained after irradiation is rescaled to its original height. With (+)-2-chloro-2-nitroso-10-bromocamphane and the pyridine salt of (+)-2-chloro-2-nitroso-10-sulphonic acid, however, the displacement of max. is accompanied by large increases in $\log I_o/I$ on the long-wave side of $\lambda$max. (below).

| Compound | $\lambda$(mμ) | Increase in $\log I_o/I$ | Minutes |
|---|---|---|---|
| B.4 | 680 | 77% | 271 |
| B.3 | 700 | 22% | 480 |

2) These changes in the spectra of B.4 and B.3 are not accompanied by inversion of the curves of rotatory dispersion as would be expected if 2:2'-mutarotation were the only cause of band displacement. The plots of $\alpha_{obs.}$ and $\log I_o/I$ against time are not parallel, the former approaching the axis of zero rotation without change of sign. This is not strictly correct since the colourless decomposition products will contribute a definite, small amount, to the final rotation. It was realised, of course, that the correction of rotation values for total photolysis (i.e., destruction of centres responsible for the blue colour) by photo-electric estimation of concentration becomes meaningless when gradual spectrum displacement takes place. It can only be carried out

accurately if the spectrum of the pure mutarotated product is determined and concentrations estimated at that wavelength where the curves of unirradiated and irradiated materials intersect. The tabulation of corrected rotations for B.2' was used to indicate the much fuller development of the Cotton effect of the product of irradiation.

3) The non-parallelism of the curves described above, however, does support the conclusion that irradiation of B.4 and B.3 is not a straight-forward elimination of the active centre responsible for a Cotton effect in the visible spectrum, but is complicated by some secondary photochemical process. These results emphasise the necessity of combined rotation and spectrum measurements in assessing the effect of irradiation on chloro-nitroso camphanes. Mitchell and Watson's conclusion (drawn from polarimetric work alone), concerning the pyridine salt of 2-chloro-2-nitrosocamphane-10-sulphonic acid, is in all likelihood correct, but it did not permit them to appreciate the complexity of the photochemical reaction.

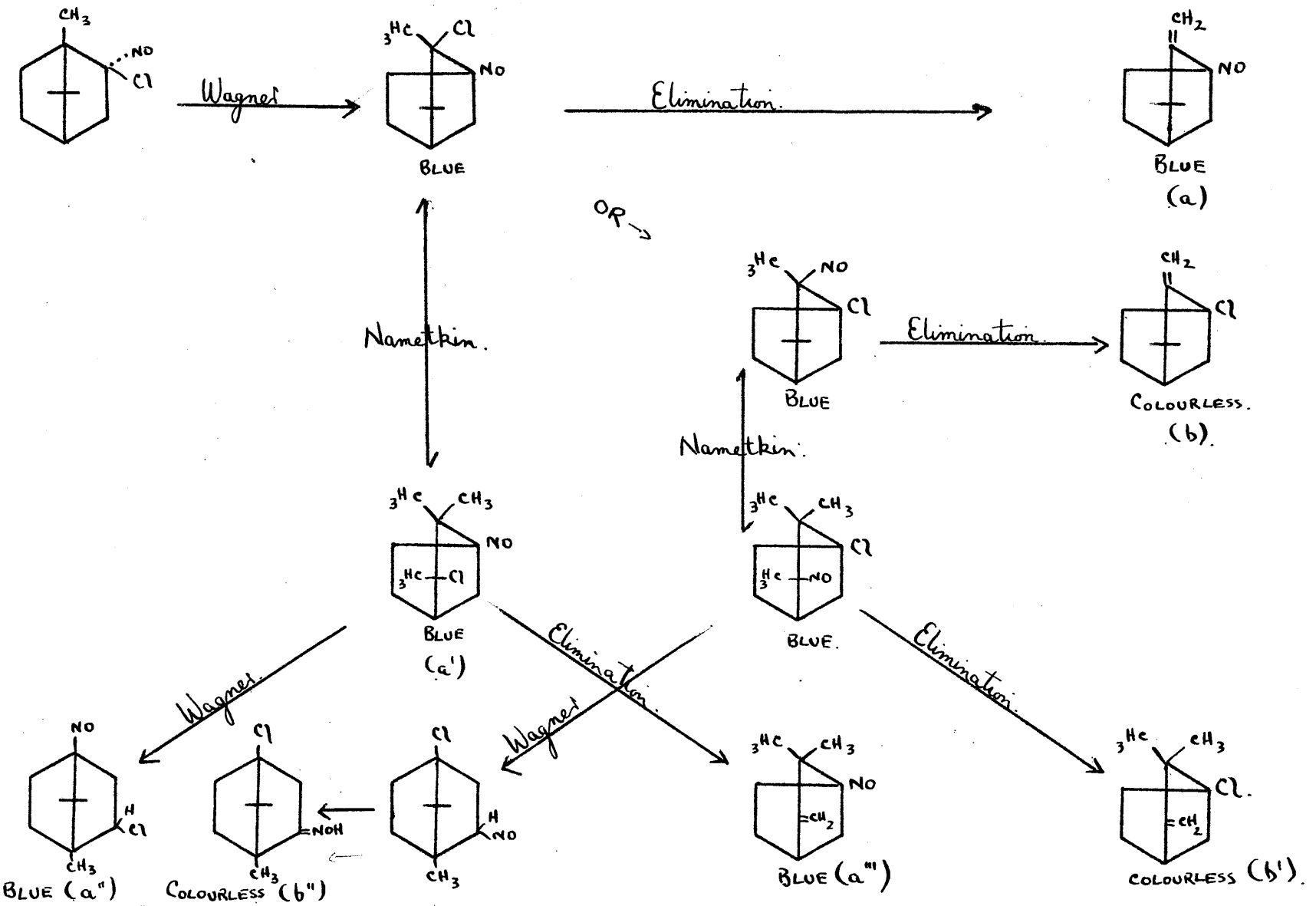
4) It has been suggested (page 68) that the sign of the Cotton effect in these molecules is determined by the configuration about $C_2$. The non-inversion of the

curves of rotatory dispersion for B.4 and B.3 implies, therefore, a preponderance of the original isomer throughout irradiation. The extent of band-displacement after short exposure to red light is too great to be accounted for by the presence of a small amount of diastereoisomer produced by 2:2'-mutarotation. It appears most probable that the shift is caused by the formation of a new blue compound (not necessarily isomeric with the original), the spectrum of which is very different from that of the 2:2'-chloro-nitroso camphane. The large effects shown by inactive 2-chloro-2-nitroso-apocamphane-1-acetic acid and its methyl ester indicates that the same photo-process probably takes place with them.

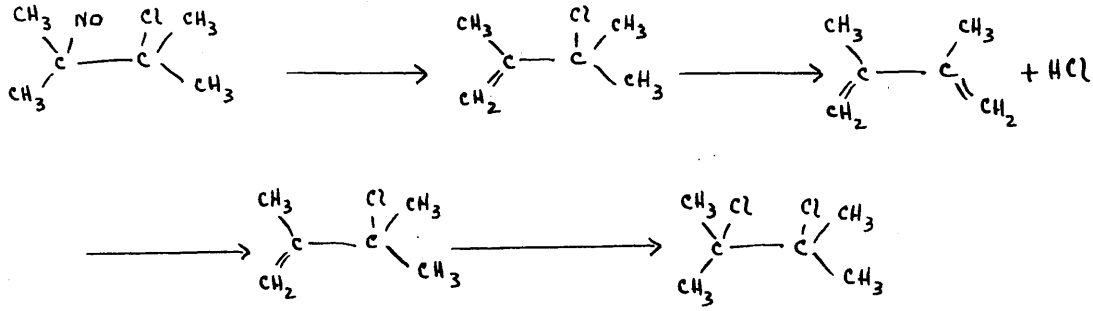
Molecular rearrangements in chloro-nitroso camphanes

A postulate of group or atom interchange in camphanes must be considered with caution, since molecules of this type are prone to Wagner-Meerwein and Nametkin rearrangements. A flowsheet is presented below, illustrating the products derived by a combination of all possible types of molecular rearrangements. The application of this concept to chloro-nitroso camphanes is supported by the following considerations:-

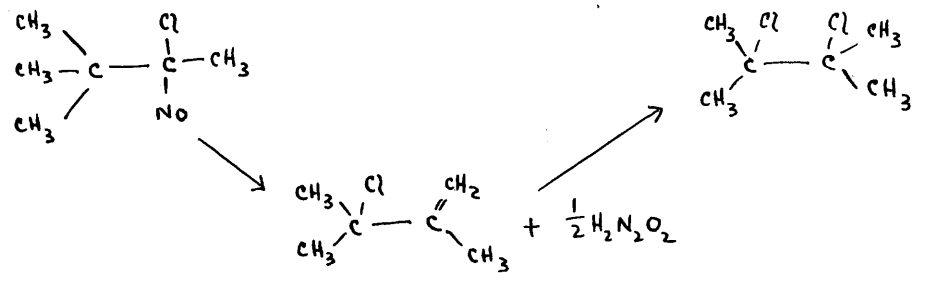
(a) 2:2'-Dichlorocamphane isomerises to give 2:4-dichlorocamphane in benzene solution with stannic chloride as catalyst. (78). This can only be accounted


Wagner
Elimination
BLUE
BLUE (a)
OR
Nametkin
Elimination
BLUE
COLOURLESS (b)
Nametkin
BLUE (a')
BLUE
Wagner
Elimination
Wagner
Elimination
BLUE (a")
COLOURLESS (b")
BLUE (a"')
COLOURLESS (b')

for by combined Wagner and Nametkin rearrangements as shown. (b) The possibility of migration of either chlorine or nitroso is considered in the flowsheet. This is justified by Hammick and Lister's work (79) on the photolysis of some chloro-nitroso and nitroso-chloride compounds. The decomposition of tetramethylethylene nitroso-chloride with red light results in the formation of tetramethylethylene dichloride, nitrogen and nitrous acid, according to the following scheme:



This implies the fission of both C-NO and C-Cl bonds. Preferential removal of NO (as hyponitrous acid) followed by rearrangement, has been observed by Naismith (48) in the photolysis of ethanolic solutions of β-chloro-β-nitroso-γγ-dimethylbutane, where nitrogen and tetramethylethylene dichloride were detected, i.e.



The following conclusions may be derived from the suggested

reaction sequences:-

(i) It is immediately obvious that the intervention of these typically terpene rearrangements can give rise to molecules in which the nitroso group is directly linked to a tertiary carbon atom and which would therefore absorb in the visible spectrum.

(ii) Several of the possible rearranged products can be formulated as nitroso-chlorides with chlorine and nitroso on different carbon atoms. By analogy with the difference in $\lambda$ max. for tetramethylethylene nitrosochloride ($\lambda$max. = 690mμ) and β-chloro-β-nitroso-γγ-dimethylbutane ($\lambda$ max. = 670mμ), it may be argued that the spectra of rearranged and unrearranged materials will be very different.

Thus, (i) and (ii) above can account qualitatively for the large changes in the spectra of B.4, B.3, B.6 and B.7.

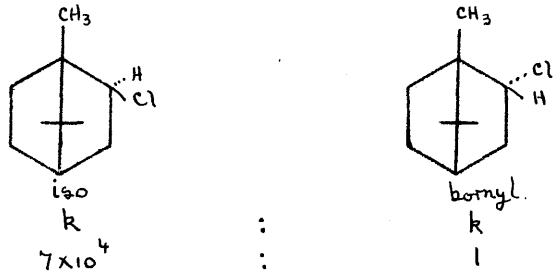
Stereo-kinetic distinction between B.1, B.2, B.2' and B.3, B.4

The concept of molecular rearrangement is developed to account for the fact that the non-inversion of the curves of rotatory dispersion of B.3 and B.4 on irradiation are accompanied by exceedingly large spectrum

changes. The skeleton of the parent camphane (B.1), with its $C_{10}$ methyl group, has also been shown (78) to undergo rearrangement so that the arguments presented above would appear, at first sight, to be equally applicable to it. Stereochemical factors alone can account for the differences in the photo-processes taking place in B.1 and B.3 or B.4. Thus,

(a) the signs of the Cotton effects of B.1 on the one hand and B.3 or B.4 on the other, are opposite so that the configurations at $C_2$ are different.

(b) the rate of unimolecular solvolysis (with re-arrangement) of isobornyl chloride with the chlorine atom cis to the gem-dimethyl bridge is 70,000 times faster than that of bornyl chloride.



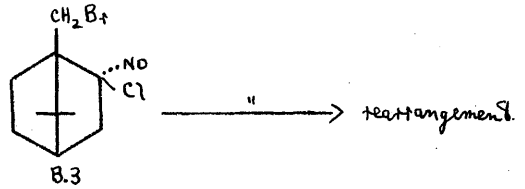

This has been interpreted (Hughes et al.) as 'synartetic acceleration' arising from the greater facility of bond-making between $C_6$-$C_2$ beneath the plane of the ring, before the receding cis-chlorine atom has reached the van der Waals distance of separation (80).

(c) the plots of $\alpha_{obs.}$ against time, obtained during the irradiation of the mixture of isomers of 2-chloro-2-nitroso-apocamphane-1-carboxylic acid (B.2) (Graph II), are consistent with the 2:2'-photomutarotation of only one of the diastereoisomers.

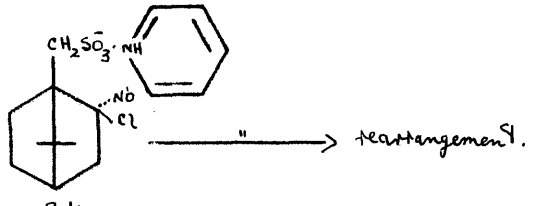
This information may account for the preferred mutarotation of B.1 and provides a basis for assigning relative configurations to the series of substituted chloro-nitroso camphanes.

Configuration and photo-process


B.1

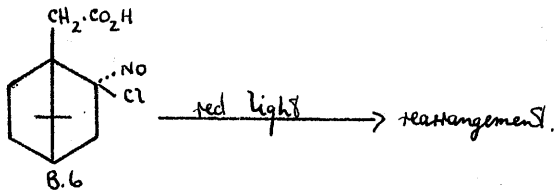



B.3

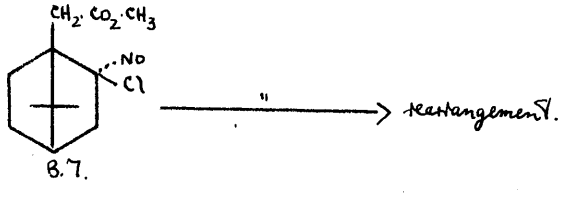



B.4

The large bathochromic shifts observed after irradiation of B.6 and B.7 support the opinion that the configurations of the d-active compounds will be identical with those of B.3 and B.4, i.e.



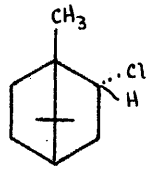

B.6



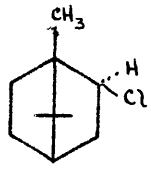

B.7.

The mutarotation of (+)-2-chloro-2-nitroso-apocamphane-1-carboxylic acid (B.2'), the $C_2$ configuration of which is the same as that for B.3 and B.4 and thus favours rearrangement, is exceptional. This compound, having no available protons, cannot eliminate hydrogen chloride after an initial Wagner rearrangement. It is conceivable therefore that, in these circumstances, the only process possible for it on irradiation with red light is 2:2'-mutarotation. It is remarkable that the spectrum of B.2', which has a $C_2$-configuration opposite that of B.1, is also displaced in the opposite direction on irradiation. It has been shown by Mitchell and Hope (75) that the direction of the displacement of the spectra of bornyl (endo) and isobornyl (exo) chlorides is the same as that shown by the mutarotation of (-)-2-chloro-2-nitroso camphane (B.1). The above authors have inferred

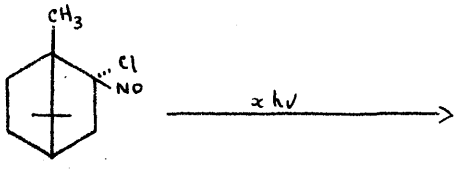
from these results a similarity in the chlorine-configuration in the two pairs of compounds.




Bornyl




Isobornyl




The configurations derived in this way agree with those presented on page 81 . The derivation of spatial configurations from spectral data is not completely justified, since the direction of spectrum displacement is determined generally by the effect of a substituent on the electronic eigenfunctions of the ground and excited levels of the absorption process, and not by molecular configurations. This has been summarised neatly by Crawford (81): "Shift of the spectrum to longer wavelengths implies a decrease in the energy-level differences between the ground and excited states. This may result either from a raising of the ground state level, a lowering of the levels of the excited states or a combination of the two. The reasons for these changes

are not as yet completely clear".

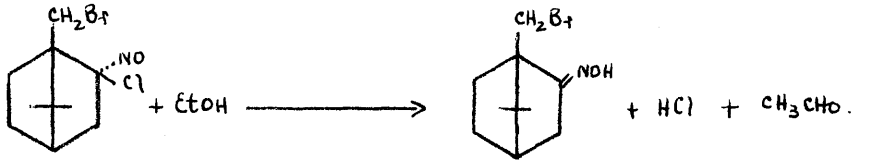
Experimental justifications for the suggested reaction sequences:-

(a) Rearrangement can, in certain cases (flowsheet), lead to products with a chlorine atom retained in the molecule. Estimation of the amount of hydrogen chloride liberated by total photochemical decomposition with red light can therefore be used to decide if rearrangement has taken place. The recovery can only be interpreted unambiguously when it is less than the theoretical amount, since rearrangement followed by elimination of hydrogen chloride would result in 100% recovery. Preliminary work on the photolysis of B.1 (82) showed that the complete removal of hydrogen chloride was not achieved. Moreover, analysis of the white, ether-insoluble photolysis product gave values for C. H and N which agreed tolerably well with those calculated for b" (flowsheet). This product differed in its chemical properties from d-camphoroxime or its hydrochloride. It is also clear that, if chloro-nitroso camphanes are capable of rearrangement initiated by visible light, then the analysis of the blue material obtained by Mitchell and Hope (75) by irradiation of B.1 cannot be taken as conclusive proof of 2:2'-mutarotation. The

fact that this material does show an inverted Cotton effect does, however, provide more convincing evidence of mutarotation since rearrangement would, in general, be accompanied by extensive racemisation.

2:2'-mutarotation of B.1 would give the diastereoisomer, the $C_2$-configuration of which would then be favourable to subsequent rearrangement.

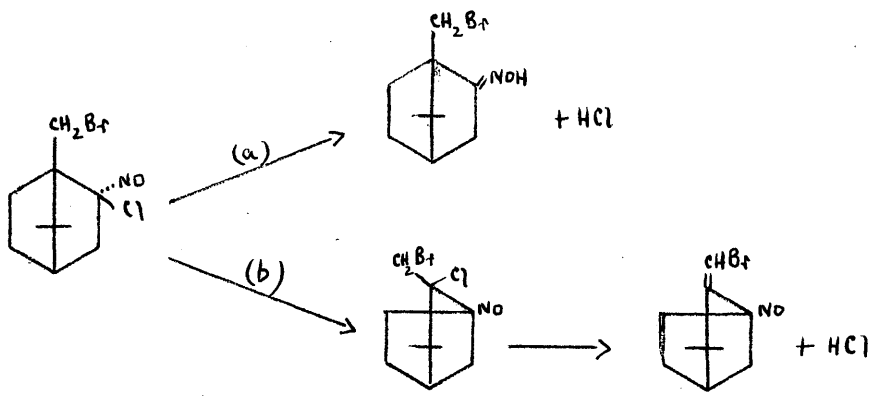
(b) Change of solvent to one incapable of yielding protons (e.g., carbon tetrachloride) should eliminate that reaction which gives unrearranged oxime or oxime hydrochloride, viz.:




and should therefore favour intermolecular rearrangement.

An 'oxygen-free', ethanolic solution of (+)-2-chloro-2-nitroso-10-bromocamphane (0.2141g.) was irradiated continuously in a sealed tube suspended in a glass tank through which water circulated. After complete discharge of the blue colour, the solution was poured into dilute ammonia solution (3ml.: 5N) and the excess of ammonia removed by gentle warming on a water bath. Direct titration with silver nitrate (0.6681g./100ml. AnalaR) gave a titre of 24.10ml., corresponding to a 99% yield of the theoretical amount of hydrogen chloride. The bromo-substituted camphane (B.3) was chosen for this experiment, since it did not

form an oxime hydrochloride and thus the possibility of a low yield due to the presence of non-ionic hydrochloride was eliminated. As shown above, this result cannot be interpreted unambiguously since the combined reaction sequence (illustrated below) can account for a theoretical yield of hydrogen chloride. The feasibility of sequence (b) is supported




by the work of Lipp (83), who showed that the action of bases on 2:10-dihalogenated camphanes (e.g., 2:10-dibromocamphane) resulted in Wagner-Meerwein rearrangement to yield the ω-bromocamphene.

The results obtained from the irradiation of B.3 in carbon tetrachloride, under conditions identical with those described previously, are set out in Table XIX. Unfortunately, the precipitation of colourless decomposition products after 390 minutes' irradiation

resulted in considerable light scattering, with consequent increases in $\log I_o/I$ at all wavelengths within the region of absorption. This is evident from the variation in $\log I_o/I$ at 580mμ where 'normal' irradiation, uncomplicated by light scattering, results in gradual decrease in absorption. The increases in $\log I_o/I$ and the displacement of $\lambda$ max, characteristic of band-shift, were observed after 180 minutes when no turbidity could be detected visually. This opacity, however, made it impossible to decide if the solvent had enhanced the degree of band-shift.

A concentrated solution of B.3 (0.5g.ca/10ml.) in ethanol was irradiated portionwise in the cell used for all previous measurements, until the value of $\log I_o/I$ at 710mμ had increased by about 25%. The solvent was removed under reduced pressure and the recovered material then passed through a column of activated alumina (Spence, 20cm. x 1 cm.), with petroleum ether (40-60°) as solvent and eluent. The simultaneous determination of the spectra of the unirradiated and irradiated materials revealed (Table XX, Graph XVI) a band-shift comparable to that obtained by the irradiation of (-)-2-chloro-2-nitrosocamphane (B.1) in which the value of [α] at 600mμ changed from +964° to approximately -500°.

TABLE XIX

Irradiation of (+)-2-chloro-2-nitroso-10-bromocamphane in carbon tetrachloride (AnalaR)

Concentration, c = 0.0699g./5ml. carbon tetrachloride (AnalaR)

t = 0.995cm.

| | $\log I_o/I$ at $\lambda$ (mμ) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mins. | 580 | 645 | 650 | 655 | 660 | 680 | 685 | 700 |
| 0 | 0.339 | - | - | - | 0.963 | 0.490 | 0.394 | 0.206 |
| 30 | - | - | - | - | 0.913 | 0.51 | 0.420 | 0.222 |
| 60 | - | 0.95 | 0.973 | - | 0.913 | 0.539 | 0.445 | 0.2445 |
| 120 | 0.305 | 0.91 | 0.925 | 0.925 | 0.90 | 0.580 | 0.489 | 0.275 |
| 180 | - | 0.875 | 0.913 | 0.913 | 0.90 | 0.618 | 0.518 | 0.2985 |
| 270 | - | 0.85 | 0.888 | 0.90 | 0.90 | 0.640 | 0.545 | 0.315 |
| 390 | 0.323 | 0.85 | 0.888 | 0.91 | 0.90 | 0.669 | 0.573 | 0.338 |

In the case of B.3, however, an initial maximum rotation of +832° at 660mμ gave, after irradiation, a value of +666° at 670mμ (c=0.0717g./5ml.; l=0.0995dm.; $\alpha_{obs.}$ = +0.94°). That is, for comparable changes in their spectra, the specific rotation of B.1 changed by some 1460° while B.3 changed by only 166°. The analyses of unirradiated and irradiated materials (below) gave values of %C and %H in agreement with those calculated for $C_{10}H_{15}ONClBr$ (i.e., B.3 or an isomer) while the total halogen content of both samples, expressed as milligrams of silver halide, was within 1.87% of the amount also calculated for $C_{10}H_{15}ONClBr$. That is, irradiation of B.3 did not result in the loss of a halogen atom to give a non-isomeric blue compound.

Analyses:-

Unirradiated :

Found : C,43.0 ; H,5.6

Calculated for $C_{10}H_{15}ONClBr$ : C,42.8 ; H,5.4

4.94mg. gave 5.720mg. silver halide.

Theoretical for $C_{10}H_{15}ONClBr$ = 5.83mg.

% difference = 1.88.

Irradiated :

Found : C,42.9 ; H,5.5

TABLE XX

Simultaneously determined spectra of unirradiated B.3 and the purified product of irradiated B.3

A unirradiated, c = 0.0704g./5ml. ethanol. M = 0.0502

B irradiated, c = 0.0708g./5ml. ethanol. M = 0.0505

t = 1cm.

| $\lambda$ (mμ) | $\log \frac{I_o}{I_A}$ | $\log \frac{I_o}{I_B}$ | $\varepsilon_A$ | $\varepsilon_B$ |
|---|---|---|---|---|
| 500 | 0.0225 | 0.0225 | – | – |
| 504 | 0.0265 | 0.025 | – | – |
| 510 | 0.0345 | 0.0325 | 0.69 | 0.64 |
| 520 | 0.0495 | 0.047 | 0.99 | 0.93 |
| 530 | 0.072 | 0.068 | 1.44 | 1.35 |
| 540 | 0.1075 | 0.101 | 2.14 | 2.00 |
| 550 | 0.141 | 0.134 | 2.81 | 2.65 |
| 560 | 0.179 | 0.174 | 3.57 | 3.45 |
| 570 | 0.234 | 0.22 | 4.66 | 4.36 |
| 574 | 0.270 | 0.25 | 5.38 | 4.95 |
| 578 | 0.301 | 0.284 | 5.99 | 5.62 |
| 580 | 0.325 | 0.304 | 6.47 | 6.02 |
| 584 | 0.364 | 0.3355 | 7.25 | 6.64 |
| 588 | 0.399 | 0.376 | 7.95 | 7.45 |
| 590 | 0.424 | 0.394 | 8.45 | 7.80 |
| 594 | 0.457 | 0.431 | 9.10 | 8.54 |
| 598 | 0.488 | 0.4625 | 9.72 | 9.16 |
| 600 | 0.500 | 0.475 | 9.96 | 9.41 |
| 605 | 0.5325 | 0.512 | 10.6 | 10.1 |
| 610 | 0.565 | 0.54 | 11.3 | 10.8 |
| 615 | 0.59 | 0.569 | 11.8 | 11.3 |
| 620 | 0.623 | 0.613 | 12.4 | 12.1 |
| 625 | 0.71 | 0.672 | 14.1 | 13.3 |

OVER:

TABLE XX (cont.)

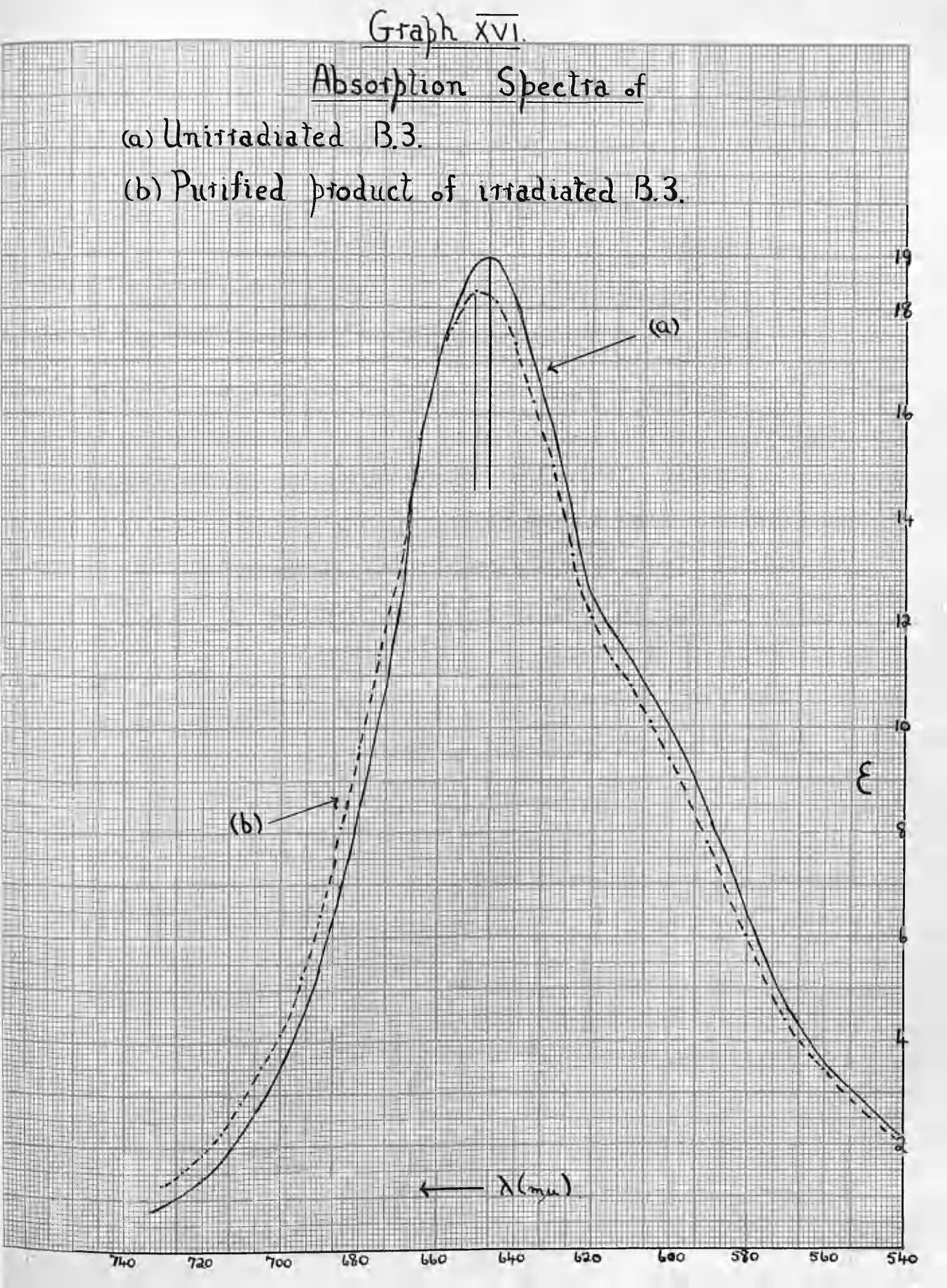
| $\lambda(m\mu)$ | $\log \frac{I_o}{I_A}$ | $\log \frac{I_o}{I_B}$ | $\varepsilon_A$ | $\varepsilon_B$ |
|---|---|---|---|---|
| 630 | 0.79 | 0.759 | 15.7 | 15.0 |
| 635 | 0.85 | 0.816 | 16.9 | 16.2 |
| 640 | 0.912 | 0.872 | 18.2 | 17.3 |
| 645 | 0.949 | 0.916 | 18.9 | 18.1 |
| 650 | 0.948 | 0.925 | 18.88 | 18.3 |
| 655 | 0.908 | 0.895 | 18.1 | 17.7 |
| 660 | 0.85 | 0.858 | 16.9 | 16.99 |
| 665 | 0.768 | 0.782 | 15.3 | 15.5 |
| 670 | 0.618 | 0.6775 | 12.3 | 13.4 |
| 675 | 0.518 | 0.573 | 10.3 | 11.4 |
| 680 | 0.4275 | 0.4875 | 8.52 | 9.65 |
| 685 | 0.35 | 0.408 | 6.97 | 8.08 |
| 690 | 0.273 | 0.324 | 5.44 | 6.42 |
| 695 | 0.22 | 0.264 | 4.38 | 5.23 |
| 700 | 0.172 | 0.2095 | 3.43 | 4.15 |
| 705 | 0.144 | 0.1775 | 2.87 | 3.51 |
| 710 | 0.1125 | 0.142 | 2.24 | 2.83 |
| 715 | 0.088 | 0.1145 | 1.75 | 2.27 |
| 720 | 0.0695 | 0.0945 | 1.38 | 1.87 |
| 725 | 0.055 | 0.078 | 1.096 | 1.55 |
| 730 | 0.046 | 0.065 | 0.92 | 1.29 |
| 735 | 0.0395 | 0.055 | 0.79 | 1.09 |
| 740 | 0.0295 | 0.0455 | 0.59 | 0.90 |

Graph XVI.

# Absorption Spectra of

(a) Unirradiated B.3.

(b) Purified product of irradiated B.3.



5.01mg. gave 5.80mg. silver halide.

Theoretical for $C_{10}H_{15}ONClBr$ = 5.91mg.

% difference = 1.86.

The suitability of the $C_1$ and $C_{10}$ substituted chloro-nitrosocamphanes for asymmetric photolysis can now be assessed. Irrespective of the required optimum conditions - that is, high values of the anisotropy factor and specific rotation - the maximum efficiency of an asymmetric photolysis depends primarily on the destruction of one centre responsible for the optical activity in the region of circular dichroism or absorption per quantum of absorbed light. That is, the quantum efficiency ($\gamma$) for the photo-process should be unity. This has been successfully realised in the aliphatic chloro-nitroso compounds described by Mitchell and his co-workers. The chloro-nitroso camphanes described in the present work fall into two distinct types, both of which are theoretically capable of asymmetric photolysis, although with greatly impaired efficiencies.

1) The irradiation of equimolecular mixtures of d-(-) and l-(+)-2-chloro-2-nitrosocamphane and d-(+) and l-(-)-2-chloro-2-nitroso-apocamphane-1-carboxylic acid would result in a mutarotation of both optical

enantiomorphs to give mixtures which would still show zero rotation and which required x quanta per molecule. The purified, irradiated mixture would then undergo normal asymmetric decomposition, even although this was accompanied by a secondary process, for example, rearrangement to give coloured intermediates absorbing in the same spectral range (see below). The true quantum efficiency would then be the sum of at least two photochemical reactions. Unfortunately, however, the optical constants of the product of mutarotation are generally inferior to those of the starting material (75), so that the rotation developed after asymmetric photolysis would be extremely small.

2) Although it took place by at least two reactions, the elimination of the active centres in (+)-2-chloro-2-nitroso-10-bromocamphane (B.3) and the pyridine salt of (+)-2-chloro-2-nitrosocamphane-10-sulphonic acid (B.4) did not result in the preliminary inversion of their Cotton effects. The curve obtained by plotting $\alpha_{obs.}$ against time of irradiation of one of the active isomers approached the axis of zero rotation or, more accurately, the rotation value contributed by the colourless decomposition products. Asymmetric photolysis of an equimolecular mixture of the d-(+) and

l-(-) enantiomorphs would therefore proceed normally, but with greatly reduced efficiency.

Addendum:-

It was later realised that an analogy existed between the postulated, isomeric intermediate (sequence 'b', page 86) and camphene hydrochloride, which can be estimated quantitatively by direct titration with alkali. The purified product of irradiated B.3, however, did not appear to contain labile hydrogen halide (silver nitrate), and doubt was cast on the interpretation of the photo-processes of B.3 and B.4 in terms of rearrangement.

Thus, in the absence of conclusive experimental evidence, the behaviour of the chloro-nitroso camphanes on irradiation can be qualitatively accounted for in terms of intramolecular rearrangement (which in turn is conditioned by the stereochemistry of the molecules) or in terms of a general 2:2'-mutarotation. On the latter basis, the large changes in the spectra of B.3 and B.4 for small changes in rotation must be attributed to considerable variation in the interaction between the NO group and the substituent when inversion of configuration takes place. The change in interaction will be greatest with increasing restriction of rotation of the substituent about the $C_1$-$C_{10}$ bond by the gem-dimethyl bridge. Moreover, small energy changes in the red region of the spectrum correspond to relatively large wavelength differences. The small changes in the spectra of B.1 and B.2, with their sterically smaller substituents and where the restriction is less, are in agreement with this concept. The non-inversion of the Cotton effects of B.3 and B.4 on irradiation may be due to the fact that the rate of photolysis (i.e., elimination of the centre responsible for the colour) is greater than the rate of photomutarotation. The effect of the substituent therefore depends largely on its influence on the entropies of activation for the two processes.

# PREPARATIONS.

THE SYNTHESIS OF OPTICALLY ACTIVE 2-CHLORO-2-NITROSO-APOCAMPHANE-1-CARBOXYLIC-ACID (X,X') (B.2.2')

Camphor-10-sulphonic acid (II). Large quantities of this material (500gm.) were prepared according to the method described by Reychler (84).

Camphor-10-sulphonyl chloride (VI). This was prepared in 98% yield by the method of Sutherland and Shriner (85), who recommend at least four moles. of purified thionyl chloride to one mole. of sulphonic acid (recrystallised from ethyl acetate).

2-Keto-apocamphane-1-carboxylic acid (ketopinic acid)(VII)

The direct oxidation of camphor-10-sulphonyl chloride (100 gm.) with alkaline potassium permanganate according to the method of Bartlett and Knox (58) gave the β-keto acid (m.p. 232-234° uncorr.) in approximately 40% yield (30gm. ca.) and this, after recrystallisation from ethyl acetate, showed $[\alpha]_{590}^{16} = +30.5°$. (c = 2.015% in absolute ethanol). Lit. $[\alpha]_{D}^{24} = +31.2°$ in ethanol.

2-Keto-apocamphane-1-carboxylic acid oxime (VIII).

The oxime, prepared in the usual manner 10% caustic soda, was purified with animal charcoal (methanol, acetone) and finally recrystallised from aqueous methanol (needles).

m.p. = 217°(uncorr.); $[\alpha]_{590}^{18} = \pm 0.00°$(c = 0.996% in absolute ethanol).

2-Keto-apocamphane-1-carboxylic acid oxime hydrochloride (IX)

The pure oxime (1gm.) was dissolved in the cold in AnalaR acetone (300ml.) and dry hydrochloric acid gas (Tucker Generator) passed into the solution at 0°C for one half hour. Removal of the solvent under reduced pressure gave an almost quantitative yield of the hydrochloride (as highly crystalline points) which, after washing with benzene (AnalaR) or dioxan (B.D.H.), melted at 214-215°C (uncorr.). A sample, vacuum dried at room temperature over calcium chloride, gave the following halogen analysis.

Found : Cl, 14.9%

$C_{10}H_{16}O_3NCl$ requires : Cl, 15.17%

2-Chloro-2-nitroso-apocamphane-1-carboxylic acid (B.2,2')

A:From the oxime in anhydrous pyridine:- All stages of this experiment were carried out in total darkness or diffuse light. The oxime (0.7gm.), dissolved in pure anhydrous pyridine and cooled to about -15°C was chlorinated slowly for six minutes. The colour became green and then deep blue almost instantaneously. The reaction mixture was then immediately poured into a separating funnel containing water covered with a layer of ether. The blue ether layer was washed repeatedly with water (total, 750ml.) and then dried over anhydrous magnesium sulphate.

Removal of the ether at the water pump gave the solid blue acid (0.5gm.), which was dissolved in benzene (AnalaR) and chromatographed through a column (16cm. x 1cm.) of 120 mesh silica gel. This removed greenish impurities. The recovered acid crystallised from a mixture of benzene and petroleum ether (60-80°) as needles which melted at 146-147°C. (uncorr.) with decomposition.

| | | | | |
|---|---|---|---|---|
| Found | : | C,51.8; | H,6.3; | N,5.9 |
| $C_{10}H_{14}O_3NCl$ requires | : | C,51.8; | H,6.1; | N,6.1 |

B:From the oxime or oxime hydrochloride in ether:-

The oxime (2gm.) or oxime hydrochloride (0.85gm. analytically pure), dissolved in ether (1 litre) which had been dried first with sodium and then by distillation from phosphorus pentoxide, was chlorinated at 0°C for three hours in total darkness. The ether was removed from the emerald-green solution by distillation from a water bath ($\not>$ 45°C) and then at the water pump. The deep blue, crude, crystalline product was purified, first by chromatography (120 mesh silica gel; benzene as solvent and eluent) and then by crystallisation from a mixture of benzene (AnalaR) and petroleum ether (60-80°).

Yield:

From oxime 1.8gm. prisms

From oxime hydrochloride 0.5gm.

m.p. 150 - 150.5°C (decomp.).

Found: C, 52.0 ; H, 6.0 ; N, 6.2

$C_{10}H_{14}O_3NCl$ requires; C, 51.8 ; H, 6.1 ; N, 6.1

Note: The difference in the melting points of A and B above emphasises that they are diastereoisomers and not enantiomorphs.

THE SYNTHESIS OF (+)-2-CHLORO-2-NITROSO-10-BROMOCAMPHANE (XVI)(B.3). Potassium salt of camphor-10-sulphonic acid (XII).

Ethanolic caustic potash was added slowly to a cooled solution of the sulphonic acid (II) in ethanol. Precipitation of the salt began almost immediately. Care was taken to leave the mixture slightly acid. This prevented the alkaline hydrolysis of the unstable sulphonyl bromide prepared as shown below.

Camphor-10-sulphonyl bromide (XIII). This was prepared according to the method of Lowry and Armstrong (86). Fresh phosphorus pentabromide (B.D.H.,100gm.) was gradually added to the dry, finely divided potassium salt (63.5gm.) in a large mortar. Each addition of bromide was carefully ground into the salt with a stiff spatula (total time of addition, two hours). The pasty, deep red reaction mixture was allowed to stand for one hour and then gradually added to a mixture of crushed ice and crystalline sodium sulphite. The water-insoluble, pale yellow sulphonyl bromide was collected by filtration, dissolved in xylene (300ml.) and dried with calcium chloride.

10-Bromocamphor (XIV). Removal of the elements of sulphur dioxide from the bromide (XIII) was effected

by boiling the dry xylene solution over a small flame for twenty minutes. The almost black solution was then steam-distilled to remove xylene and, finally, the lachrymatory bromo-ketone (16gm.). Recrystallisation from ethanol gave the ketone (needles) melting at 77°C.

10-Bromocamphor oxime (XV). The ketone (7.2gm.), hydroxylamine hydrochloride (8gm.) and anhydrous pyridine (70ml.) were heated on the water bath (100°C) for three hours. The cooled reaction mixture (two layers) was then poured on to crushed ice and the precipitated oxime (5.7gm.) collected, dried and recrystallised from ethanol (plates). m.p. 156°C $[\alpha]^{18}_{590} = -72°$ ($\alpha = -0.50°$, c = 0.0696g/10ml. $CHCl_3$.l = 1dm.)

(+)-2-Chloro-2-nitroso-10-bromocamphane (B.3). All stages of this experiment were carried out in total darkness or diffuse light. The bromo-oxime (2gm.), dissolved in anhydrous ether (150ml.), was cooled in an ice bath and dry chlorine passed in at a moderate rate for two hours. Removal of the ether (water bath, 45°) always yielded a deep blue viscous oil, which could only be induced to solidity after passage through a column of activated, unwashed alumina

(30cm. x 1 cm. : petroleum ether (40-60°) as solvent and eluent). It was soluble in all solvents at room temperature but could be crystallised from petroleum ether (40-60°) by allowing it to stand overnight in the refrigerator. Plates, m.p. 131-133°C (decomp. : uncorr.).

| | | | | |
|---|---|---|---|---|
| Found | : | C, 43.2 ; | H, 5.6 ; | N, 5.2 |
| $C_{10}H_{15}ONClBr$ requires | : | C,42.8 ; | H, 5.4 ; | N, 5.0. |

THE SYNTHESIS OF OPTICALLY INACTIVE 2-CHLORO-2-NITROSO-APOCAMPHANE-1-ACETIC ACID (XXXI) (B.6)

10-Benzoyl borneol (XXV) was prepared by the gradual addition of finely powdered aluminium chloride (132gm.) to a solution of Light's inactive camphene (100gm.) and re-distilled benzoyl chloride (85.2ml.) in AnalaR carbon disulphide kept at about -10°C (ice and concentrated hydrochloric acid) and protected from moisture by a silica gel drying tube. Vigorous shaking was maintained during the addition of the catalyst (total time about one hour). Precipitation of the complex started after about fifteen minutes and was accompanied by a marked darkening of the solution. The dark brown, granulated complex was allowed to stand for fifteen minutes to complete the reaction and then decomposed by pouring on to crushed ice. The hydroxy-ketone was extracted with ether, washed five times with liberal amounts of dilute hydrochloric acid and then twice with dilute sodium carbonate. Removal of the ether and carbon disulphide at the pump gave a dark brown oil which was steam-distilled rapidly in the presence of solid sodium carbonate (30gm.) for two hours. The residue (pale yellow) solidified on rapid cooling and after two recrystallisations from petroleum ether,

(80-100°) the benzoyl borneol (66gm.) was obtained as white needles melting at 84-87°C (uncorrected).

10-Benzoyl borneol oxime (XXVI). Hydroxylamine hydrochloride (19gm. 40% excess) in the minimum amount of water was added to a solution of potassium acetate (38gm.) in warm ethanol (125ml.). The filtered solution was then added to the hydroxy-ketone (50gm.) in ethanol (100ml.) and heated under reflux for three hours. The oxime (50gm.), precipitated with water, was recrystallised from aqueous methanol (with considerable loss) to give a pale brown product (40gm.) melting at 159-160°C (uncorrected).

2-Hydroxy-apocamphane-1-acetanilide (XXVII). The thoroughly dried oxime (35gm. 0.12mole.) was dissolved in anhydrous ether (400ml.) by heating under reflux. To this solution initially at about 15°C, was gradually added over a period of one hour, powdered phosphorus pentachloride (77gm. 0.37mole.). At no time during the addition of catalyst was the temperature allowed to rise above 24°C and ice-cooling was applied to ensure that this limit was not exceeded. The pale yellow solution became very turbid after fifteen minutes, but cleared with further addition of chloride. After standing at room temperature (18°C) for not

longer than two hours (minimum, one hour) the brown ether layer was poured on to water. The solid phosphorus pentachloride was then gradually added to crushed ice covered with ether. The combined ether layers (about 700ml.) were then washed repeatedly with water to remove hydrochloric acid. This resulted in the precipitation of 10gms. of anilide which was separated by filtration. Removal of most of the ether yielded a further amount of product (4gm.). The water extracts (four litres) were allowed to stand overnight when 5gms. of white anilide were deposited. Recrystallisation from aqueous ethanol gave thick needles of the anilide (17gm.) melting at 176-177°C (uncorrected).

Lactone of 2-hydroxy-apocamphane-1-acetic acid (XXVIII). The anilide (recrystallised once) (11gm.) was dissolved in filtered ethanolic potash solution (390ml. of 20% potassium hydroxide) and heated under reflux for six hours. This was poured, after cooling, into water (1200ml.) and extracted four times with 200ml. portions of ether. The volume of the aqueous layer was reduced by distillation under reduced pressure from large volume Quickfit apparatus (to eliminate loss from frothing and 'bumping'). An atmosphere of inert gas above the liquid was found unnecessary. The cooled, acidified aqueous layer was extracted four times

with ether, and the ether extract dried over sodium sulphate. Removal of the ether at the water pump gave 7gm. of dark brown oil which slowly solidified with prolonged suction at 100°C. Removal of the elements of water with acetyl chloride was found to be unnecessary. Chromatography of the crude lactone through 120 mesh silica gel, with chloroform as solvent and eluent, gave a white product (6gm.) which, after crystallisation from aqueous ethanol or petroleum ether, melted at 196-198°C (uncorr.) with shrinking about 120°C (lit. 201.5-202.5). Opaque needles.

Found: C, 73.1 ; H, 8.7

Calculated for $C_{11}H_{16}O_2$: C, 73.3 ; H, 8.9

2-Keto-apocamphane-1-acetic acid (XXIX). The lactone (4gm.) was dissolved with heating in 2% aqueous caustic potash (80ml.) and allowed to cool to room temperature. A solution of potassium permanganate (3.51gm.: 1 mole. in about 60ml. of water) was gradually added to the stirred alkaline solution over a period of five hours. The temperature was then slowly raised to about 60°C, when the colour was quickly discharged. After filtration to remove manganese dioxide, the volume of the liquid was reduced to about one half by distillation, cooled, acidified with 1:1 hydrochloric acid and extracted four

times with ether. Removal of the ether (dried over sodium sulphate) on the water bath gave a clear, viscous oil which solidified after seeding and leaving overnight at 0°C. Trituration with petroleum ether (60-80°) gave the ɣ-keto acid as a white powder (3.5gm.) melting at 82-86°C. The melting point was raised to 92°C (uncorr.) by crystallisation from a mixture of benzene and petroleum ether (60-80°). Points.

Found: C, 67.1 ; H, 7.9

Calculated for $C_{11}H_{16}O_3$: C, 67.3 ; H, 8.2

2-Keto-apocamphane-1-acetic acid oxime (XXX). A solution of the keto-acid (4gm.) and hydroxylamine hydrochloride (4gm.) in aqueous caustic potash (60ml., 10%) was heated under reflux for seven hours, cooled and carefully acidified with dilute hydrochloric acid. The finely divided oxime was then filtered, dried and recrystallised from aqueous ethanol. Yield, 3gm. Prisms.

2-Chloro-2-nitroso-apocamphane-1-acetic acid (B.6). All stages of this experiment were carried out in total darkness or diffuse light. The thoroughly dried oxime (2gm.) was dissolved in sodium-dried ether (600ml.) and cooled to 0°C. After the passage of dry chlorine for two hours, the ether was removed from the emerald-green solution, first by distillation from a water bath

(↗45°C) and then at the water pump. The resulting deep blue crystalline solid was dissolved in benzene and chromatographed through a column of 120 mesh silica gel (30cm. x 1cm.). The recovered material (1.4gm.) crystallised from a mixture of benzene and petroleum ether (60-80°) in small hard prisms, melting at 128-129°C. (uncorr.) with decomposition.

Found: C, 53.9 ; H, 6.4 ; N, 5.8

$C_{11}H_{16}O_3NCl$ requires: C, 53.8 ; H, 6.6 ; N,5.7

Note:

Attempts to prepare (XXXl) by chlorination of the oxime in anhydrous pyridine (cf. B.2', p.93 ) at -15°C. resulted in the formation of dark brown decomposition products.

OPTICALLY INACTIVE 2-CHLORO-2-NITROSO-APOCAMPHANE-1-METHYLACETATE (XXXIV).

2-Keto-apocamphane-1-methylacetate (XXXII)

The ϒ-keto acid (XXIX) (3.2gm.) was dissolved in methanol (50ml.), saturated with dry hydrogen chloride (Tucker Generator) and allowed to stand at room temperature for 24 hours. Most of the solvent was removed by distillation (atmospheric) and the residue dissolved in ether, washed four times with 10% sodium bicarbonate solution and dried over sodium sulphate. Removal of the solvents gave an oil (2.7gm.) which did

not react with bicarbonate solution.

The oxime of 2-keto-apocamphane-1-methylacetate (XXXIII)

The crude ester (2.7gm.), dissolved in a filtered methanolic solution (30ml.) of hydroxylamine hydrochloride (3gm.) and potassium acetate (7gm.), was heated under reflux for 8 hours. Most of the methanol was then removed by distillation and the cooled residue poured into water and extracted with ether. Removal of the dried ether at the water pump yielded 2.3gm. of a pale yellow, viscous oil. A small quantity of this solidified after scraping with methanol on a watch glass (m.p. 61-66°C) and was used to seed the bulk. No attempt was made to purify the oxime by crystallisation.

2-Chloro-2-nitroso-apocamphane-1-methylacetate (XXXIV)(B.7).

The crude oxime, dissolved in ether (175ml.) which had been dried first by sodium and then by distillation from phosphorus pentoxide, was chlorinated at 0°C for one-and-a-half hours. Removal of the ether by distillation from a water bath ($\not>$ 45°C), and then at the water pump, gave a small amount of deep blue oil, which was passed through a column of silica-gel (50-100 mesh) with benzene as solvent and eluent. The solvent was removed at the water pump (bath $\not>$ 52°) and then at a pressure of

0.5mm.Hg. The blue residue was allowed to stand overnight in the refrigerator and the resulting sticky solid was dried by pressing on porous plate. It was readily soluble in most solvents, and an analytical sample could be prepared only by further treatment with silica-gel, followed by high vacuum removal of the solvent. Analysis confirmed that it was the required 2-chloro-2-nitroso-apocamphane-1-methylacetate (m.p. 55-58° C).

| | | | |
|---|---|---|---|
| Found: | C, 55.7 | ; H, 7.2 | ; N, 5.2 |
| $C_{12}H_{18}O_3NCl$ requires : | C, 55.5 | ; H, 7.0 | ; N, 5.4 |

ATTEMPTED SYNTHESIS OF OPTICALLY ACTIVE 2-CHLORO-2-NITROSO-APOCAMPHANE-1-ACETIC ACID (XXXI) (B.6).

A - The cyclic ethylene ketal of 10-bromocamphor (XVII) (87)

Ethylene glycol (10ml. ca.) and p-toluene sulphonic acid (200mg.) were added to a solution of the bromo-ketone (32.5gm.) in sodium-dried benzene (80ml.). This two-phase system was then heated in an oil bath at 110-120° for about 34 hours. Water formed during the reaction was collected in a trap attached to the flask (Organic Syntheses, 23, 38). At the end of this time, the reaction mixture was quite homogeneous and the amount of water collected corresponded to about twice the theoretical amount. The cooled mixture was then washed with water to remove the catalyst and dried over anhydrous sodium sulphate. The oily residue obtained after removal of the solvent at the water pump was subjected to high-vacuum distillation and yielded the cyclic ketal in 83% yield.

B.p. 114°C (oil bath)/0.5mm.Hg. : $n_D^{20}$ 1.5197.

The ketal was stable to alkali but was readily hydrolysed to the ketone by gentle warming in dilute methanolic sulphuric acid (1ml. $H_2SO_4$ to 22ml. MeOH).

B - Reaction of n-butyllithium with the bromo-ketal (88)

Lithium metal (2.13gm.), hammered flat between

sheets of cardboard soaked in petroleum ether (80-100°), was scraped under a solvent to expose the clean surface, washed in ether and then cut into small pieces which were allowed to fall into a silica-gel protected flask, containing anhydrous ether (30ml.) under an atmosphere of dry nitrogen. A concentrated solution of n-butyl bromide (17gm. 0.12mole.) in dry ether was slowly added from a dropping funnel, and the solution stirred (Hersberg) at 0°C until complete solution of the metal had been effected (50 minutes). The dark-grey solution was then allowed to come to room temperature, when the bromo-ketal (13.75gm.) in ether was added over a period of 20 minutes. There was no obvious colour change. Stirring under a stream of nitrogen was maintained for a further hour and the reaction mixture then poured on to dry, solid carbon dioxide (160gm.). The ethereal solution was extracted with dilute caustic soda and the extract then acidified with hydrochloric acid and extracted four times with ether. Removal of the ether (dried over sodium sulphate) gave a small amount of a pale brown oil (2.3gm.), which was dissolved in methanolic sulphuric acid (22ml. 1ml. $H_2SO_4$ to 22ml. MeOH), heated on the water bath (60°C) for 6 hours and then poured into water. The resulting water-insoluble oil was

extracted with ether and dried with sodium sulphate. Removal of the ether at the water pump gave a small amount of oil which crystallised from aqueous ethanol (3 EtOH : 1 $H_2O$) as fine lustrous needles melting some 70° higher than the inactive $\gamma$ -keto acid (XXIX), at 163-165°C. Analysis of this alkali-insoluble material gave values for carbon and hydrogen intermediate to those required by the keto-acid and its methyl esters:

| | | |
|---|---|---|
| Found: | C, 68.1 ; | H, 8.0 |
| Keto-acid requires : | 67.3 ; | 8.2 |
| Methyl ester requires : | 68.5 ; | 8.6 |

8.2gm. of the unreacted bromo-ketone were recovered from the original ethereal mother liquors.

C - Reaction of the bromo-ketone with cuprous cyanide (65)

An intimate mixture of the ketone (6gm. 0.026mole.), dry cuprous cyanide (2.87gm. 0.032mole.) and pure anhydrous pyridine (3ml.) were heated in a Woods metal bath at 210-220°C for 18 hours. The reaction mixture, cooled to about 100°C., was then poured into ammonia. The dark brown solid was ground under this solvent, extracted with benzene and steam-distilled. No trace of the cyano compound was obtained.

## THE SYNTHESIS OF OPTICALLY INACTIVE 2-CHLORO-2-NITROSO-10 BENZYLCAMPHANE (XXXIX) (B.8).

### 10-Benzylborneol. (XXXVI).

Modified Huang-Minlon Reduction: The hydrazone (XXXV) of 10-benzoyl borneol (XV) was prepared by adding 100% hydrazine hydrate (2gm.) to an ethanolic solution of the hydroxy-ketone (12gm.). This was heated to the boiling point for two or three minutes and allowed to cool. The hydrazone (5.5gm.) crystallised (pale yellow needles) immediately, and a further amount of product (3gm.) was obtained by addition of water to the ethanolic mother liquors. Crystallisation from aqueous ethanol gave white needles of the hydrazone melting at 163-164° (uncorr). The dry hydrazone (5.5gm.) was dissolved in alkaline diethylene glycol (55ml.-3.4gm. KOH, i.e. three equivalents) by heating to a temperature not exceeding 100°C. The pale brown solution, in an open vessel, was then heated slowly in an oil bath to a temperature of 190-200°C, which was maintained for two hours. Gas evolution, which began at 130°C, became brisk at 180° and ceased after about forty minutes, with an almost simultaneous deepening in colour. The partly neutralised reaction mixture was cooled, poured into water (350ml) and extracted four times with ether.

Removal of the ether (dried over sodium sulphate) gave a pale brown oil (5.1gm.) which could not be induced to crystallise. Distillation gave 3.9gm. of product boiling at 156-166°C (oil bath)/0.6mm.Hg. The 10-benzyl borneol was characterised by its phenylurethane (small points) which, after four crystallisations from petroleum ether (80-100°) melted at 139-140°C (uncorr.).

Found: C, 79.3 ; H, 7.7 ; N, 4.1

$C_{24}H_{29}O_2N$ requires: C, 79.4 ; H, 8.0 ; N,3.9

10-Benzyl camphor (XXXVII). Chromic anhydride (2.4gm. dissolved in 4ml. of water and 8ml. of glacial acetic acid in that order) was added, drop by drop, to a solution of the alcohol (3.8gm.) in glacial acetic acid (10ml.). The rate of addition was controlled so that temperature did not rise above 35°C. No spontaneous increase in temperature was observed after the addition of 75% of the chromic anhydride. The remainder was then added and the temperature slowly raised to about 80°, where it was maintained for one half hour. The reaction product was poured into an excess of water, carefully neutralised with solid sodium carbonate, and extracted five times with ether. Removal of the ether (dried over sodium sulphate) gave an oil (3gm.) which could not be crystallised. Distillation

afforded 2gm. of the ketone, boiling at 150-152° (oil bath)/0.7mm.Hg.

10-Benzyl camphoroxime (XXXVIII). A mixture of the above ketone (0.7gm.) and hydroxylamine hydrochloride (1gm.) in anhydrous pyridine (8ml.) was heated on the water bath (100°C) for four hours. The cooled mixture (two liquid phases) was poured on to crushed ice and the precipitated oxime removed by filtration. Crystallisation from petroleum ether (80-100°) gave 0.5gm. of the oxime as fine, matted needles melting at 127-127.5° (uncorr.).

| | | | | |
|---|---|---|---|---|
| Found | : | C, 79.3 ; | H, 9.1 ; | N, 5.9 |
| $C_{17}H_{23}ON$ requires | : | C, 79.3 ; | H, 9.0 ; | N, 5.4 |

2-Chloro-2-nitroso-10-benzylcamphane (XXXIX). All stages of this experiment were carried out in total darkness or diffuse light. The oxime (XXXVIII, 0.8gm.), dissolved in ether (200ml.) which had been dried first with sodium and then by distillation from phosphorus pentoxide, was chlorinated rapidly for two and a half hours at -10°C (ice and salt). The rate of formation of the blue compound was extremely slow. No green colour had developed after the first hour. Removal of the ether by distillation from water bath (45°) and then at the water pump gave a small amount of

deep blue oil. Dissolution in petroleum ether (60-80°) resulted in the precipitation of a relatively large amount of white material which was removed by filtration. This was presumably the original oxime, since no oxime hydrochloride was obtained by the passage of dry hydrogen chloride (Tucker Generator) into a cooled, concentrated, ethereal solution of the oxime. Removal of the solvent (after chromatography through a column of unwashed, activated alumina) at the water pump and then at 0.5mm. Hg., gave a small amount (0.35gm.) of extremely viscous blue oil which was used as such for photochemical work.

## THE ATTEMPTED SYNTHESIS OF OPTICALLY ACTIVE 2-CHLORO-2-NITROSO-10-HYDROXYCAMPHANE (XXIII) (B.9).

10-Acetoxycamphor (XX). This was prepared from 10-bromocamphor (XIV) according to the method described by Iki (69). The crude reaction product viscous oil distilled at 108-109°/1.55mm.Hg., but solidified after standing for a few hours in the refrigerator. Recrystallisation from petroleum ether (40-60°) at 0°C gave well developed, long needles which slowly dissolved at room temperature. A sample of the solidified distillate, after washing with ether, gave the following analysis:

| | | | | |
|---|---|---|---|---|
| Found | : C, 68.4 ; | H, 8.4 ; | m.p. 28-29°C (uncorr.) |
| Calculated for $C_{12}H_{18}O_3$ | : C, 68.5 ; | H, 8.6 | |

10-Hydroxycamphor (XXI). Hydrolysis of the ester (XX) with ten per cent ethanolic caustic potash gave a good yield of the crude hydroxy-ketone (pale yellow). No attempt was made to purify it as described by Iki.

10-Hydroxycamphoroxime (XXII). The ketone (2gm. in 60ml. of water), hydroxylamine hydrochloride (2gm.) and caustic soda (10ml. of 10% NaOH aq.) were heated under reflux for seven hours. The mixture was then extracted five times with ether, and the extract dried over sodium sulphate. Removal of the ether gave the oxime (1.8gm., white solid), which crystallised from

petroleum ether (60-80°) in fine, non-lustrous, needle clusters melting at 178-179° (uncorr.), with shrinking at about 100°C.

Found : C, 65.9 ; H, 9.3 ; N, 7.5

$C_{10}H_{17}O_2N$ requires : C, 65.6 ; H, 9.3 ; N, 7.7

2-Chloro-2-nitroso-10-hydroxycamphane (B.9). Three methods of preparing the blue hydroxy compound were attempted:-

(a) In anhydrous ether:

Chlorination of the hydroxy-oxime (0.5gm.) in anhydrous ether (25ml.) resulted in the immediate precipitation of a white flocculent solid, which re-dissolved on the addition of more ether (200ml.). Rechlorination (one hour) finally yielded a very pale green solution. The residue, obtained by removal of the ether, was a pale blue, wax-like solid unsuitable for photo-chemical work.

(b) In anhydrous pyridine:

Chlorination for approximately five minutes at -15°C resulted in the formation of dark brown decomposition products.

(c) In dilute hydrochloric acid:

The hydroxy-oxime, dissolved in dilute hydrochloric acid covered with a layer of ether, was chlorinated rapidly for fifteen minutes. The pale green, ether layer

was separated, dried and finally evaporated, leaving a blue wax-like solid similar to that obtained in (a) above.

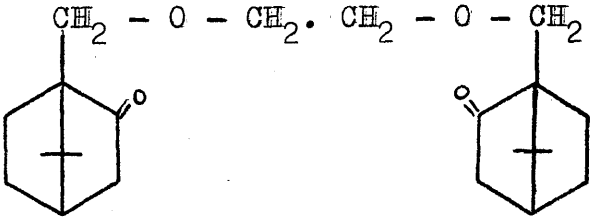
ATTEMPTS TO PREPARE THE CYCLIC ETHYLENE KETAL (XXIa) OF 10-HYDROXY CAMPHOR.

Ethylene glycol (12ml.) and p-toluene sulphonic acid (0.5 gm.) were added to the crude hydroxy-ketone (25.5gm.) dissolved in sodium-dried benzene (85ml.). The mixture was heated in an oil bath at 110-140°C for 38 hours, when 4.3ml. of water were collected in the trap described in the preparation of the bromo-ketal. A large amount of matted needles separated when the reaction mixture was allowed to cool, but they dissolved readily when the solvent was removed at the water pump. Vacuum distillation of the residue gave a small amount of water-insoluble oil (2.6gm.), boiling at 60-63°/1.7mm. Hg ($n_D^{20}$ = 1.4400. $n_D^{20}$ of glycol used = 1.4311). Distillation was discontinued when the bath temperature reached 120°C. The sticky solid residue was dissolved in ether, filtered and dried over sodium sulphate. Removal of the ether gave an appreciable amount (20gm.) of a rather sticky solid, which could not be induced to crystallise from the usual solvents. A sample of this material was sublimed on to a cold finger (80-90° (oil bath)/1mm. Hg)

and submitted for analysis. The values of % carbon and hydrogen obtained for this crystalline, water-insoluble material, which resembled camphor in appearance, approximated to those required by the di-ether (below) formed by inter-molecular condensation of the ketone through its hydroxy group, viz.:

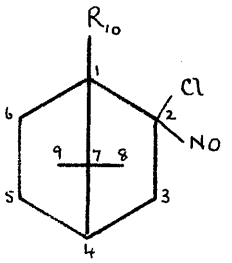
Found : C, 69.84 ; H, 9.26

$C_{22}H_{34}O_4$ requires : C, 70.98 ; H, 10.13



## SUMMARY.

The following $C_1$, $C_{10}$ - substituted chloro-nitrosocamphanes have been synthesised:-




(a) R = $CO_2H$

(b) " = $CH_2Br$

(c) " = $CH_2CO_2H$

(d) " = $CH_2CO_2Me$

(e) " = $CH_2CH_2Ph$

The effect of irradiation with polychromatic red light was determined by both spectrophotometric and polarimetric measurements. The absorption spectra of compounds (b) - (e) showed bathochromic shifts after short exposure while that shown by (a) was hypsochromic. The reinvestigation of the spectra of the previously described chloro-nitrosocamphanes (f) and (g) (R = Me and $CH_2SO_3^-$ $NH^+$.Py respectively), also revealed changes in $\lambda$ max. after irradiation. Thus all chloro-nitrosocamphanes investigated showed, to varying degrees, changes in their spectra after irradiation.

The Cotton effects and $C_2$ - configurations of (a), (b) and (g) were opposite those for the parent camphane (f). The irradiation of (a) and (f) resulted in the rapid inversion of their initially opposite curves of rotatory dispersion with a simultaneous displacement of their

spectra in different directions. These observations are interpreted in terms of a 2:2' - mutarotation which gives the diastereoisomer with different molecular constants and hence a different spectrum.

The polarimetric and absorption measurements for (b) and (g) however, are not easily reconciled with this hypothesis. Irradiation resulted in much greater increases in absorption on the long-wave side of $\lambda$ max., while their Cotton effects did not change sign. Indeed for comparable changes in their spectra, the rotation of (b) changed by only 166° compared with the 1460° shown by (f). Various alternative causes of band-shift are discussed and shown by experiment to be untenable.

The possibility of Wagner-Meerwein and Nametkin rearrangements induced by light is discussed and shown to provide a qualitative interpretation of the differences in the photo-processes of (b) and (g) on the one hand and (a) and (f) on the other. On this basis, the stereochemistry of the molecules determines the nature of the process. Experiments, in which it was hoped to differentiate between photomutarotation and intramolecular rearrangement in (b) and (g), are described. Although it was shown that, like (f), the product of irradiation of (b) was isomeric with the starting

material, the results of these experiments are inconclusive.

The substituted chloro-nitrosocamphanes are shown to be theoretically capable of asymmetric photolysis but with greatly impaired efficiency.

Additional paper on :

# THE PHOTOELECTRIC POLARIMETRY AND LOW-TEMPERATURE ABSORPTION SPECTROSCOPY OF (-)-β-CAROPHYLLENE NITROSITE.

All optically active, monomeric nitroso compounds show selective absorption in the spectral range 500-750mμ. The wavelength of zero rotation corresponds approximately to that of maximum absorption, so that one half of a curve of anomalous rotatory dispersion can be situated in the near infra-red. Visual polarimetry in this region is impossible and other methods of measurement must be adopted. Photographic methods, applied successfully to the ultra-violet (89, 90), have proved inadequate (Mitchell, private communication) because of the very uneven response of photographic plates sensitised to 1200mμ.

The application of photoelectric techniques offers the most convenient alternative. There are, however, disadvantages:-

(a) All photoelectric cells have a maximum sensitivity - generally over a small spectral range - so that the determination of rotatory dispersion will probably require more than one cell.

(b) The limit of useful response of photocells is approximately 1200mμ.

(c) In order to approach the accuracy of visual measurements, several stage amplifications must be introduced. The proportionality between photoelectric current and incident light intensity does not hold if

the amplification is excessive (e.g. x $10^7$) (91).

(d) The sensitive layer of a photocell can be anisotropic. As suggested by Heller (92) and Kortüm (93), the polariser should be rotated. If this is impossible the photocell should be rotated with the analyser.

Unlike the human eye, a photocell cannot compare two light intensities in a single operation. It is therefore evident that true "half-shadow" methods cannot be applied to single-photocell instruments. Moreover, the relationship between I (the intensity) and $\sigma$ (the angle between the direction of extinction of the analyser and the direction of vibration of the incident beam) becomes of fundamental importance in photoelectric polarimetry, viz.:

$$\frac{dI}{d\sigma} = \frac{Ii\ d(\sin^2\sigma)}{d\sigma}$$

Thus a photoelectric polarimeter is most sensitive when $\sigma = 45°$.

This principle was incorporated in the earliest photoelectric polarimeters described by Halban and Siedentopf (94), Mayrhofer, Ebert and Kortüm (95). These instruments, however, were unable to differentiate between the change in photoelectric current due to rotatory power and that due to variation in the light absorption of an active compound. The determination of

a Cotton effect was therefore impossible. Bruhat and Guinier (96) eliminated this difficulty in their instrument, in which a single field analyser is preceded by a biquartz plate. The latter consists of plates of dextro - and laevo-quartz of exactly the same thickness, cut perpendicular to the optic axis and joined edge to edge. Each half produces an equal and opposite rotation so that, with the analyser and polariser 'crossed', the light incident on the single photocell will have the same intensity whichever half of the plate it traverses. An amplification factor of $10^7$ was used but, as Bruhat emphasised, such an instrument can only be operated in the complete absence of extraneous vibrations.

The optical and photoelectric systems of the Unicam S.P. 500 spectrophotometer were found to be suitable for photoelectric polarimetry. In this instrument, light from a six-volts tungsten coil lamp (D.C.) traverses an efficient Littrow monochromator, graduated in 5mμ/division from 625mμ to 1000mμ. The amount of light incident on silica-gel protected vacuum phototubes is controlled by a spring-loaded, curved, symmetrical exit slit. The spectral distribution per millimetre of slit width is 43mμ at 650mμ. Designed to measure the variation of absorption with wavelength, this instrument

is therefore suitable for the photoelectric polarimetry of compounds exhibiting a Cotton effect. The amplification factor ($\times 10^6$ a.) for the photocell falls within the limits necessary for the aforementioned relationship between current and light intensity. Furthermore, it operates on a "null-point" basis, thus eliminating the interpolations required by the methods of Bruhat and other workers, where the "kick" of a galvanometer or electrometer was recorded.

Between the exit slit and the cell compartment of the Unicam instrument, there is a passage into which a polarising prism (square-faced Glazebrook) can be fitted. The brass polarising unit used is that described by Mitchell (97) for the photoelectric determination of circular dichroism (see p.130). The cell compartment, however, is not long enough to accommodate the other prism as well as the observation cell, so that the analyser has to be housed in a light-tight unit fixed between the cell compartment and the photocell box. The analyser unit, described previously by Mitchell and Veitch (98), has since undergone considerable modification and refinement. This is incorporated in the following description (See diagrams A and B).

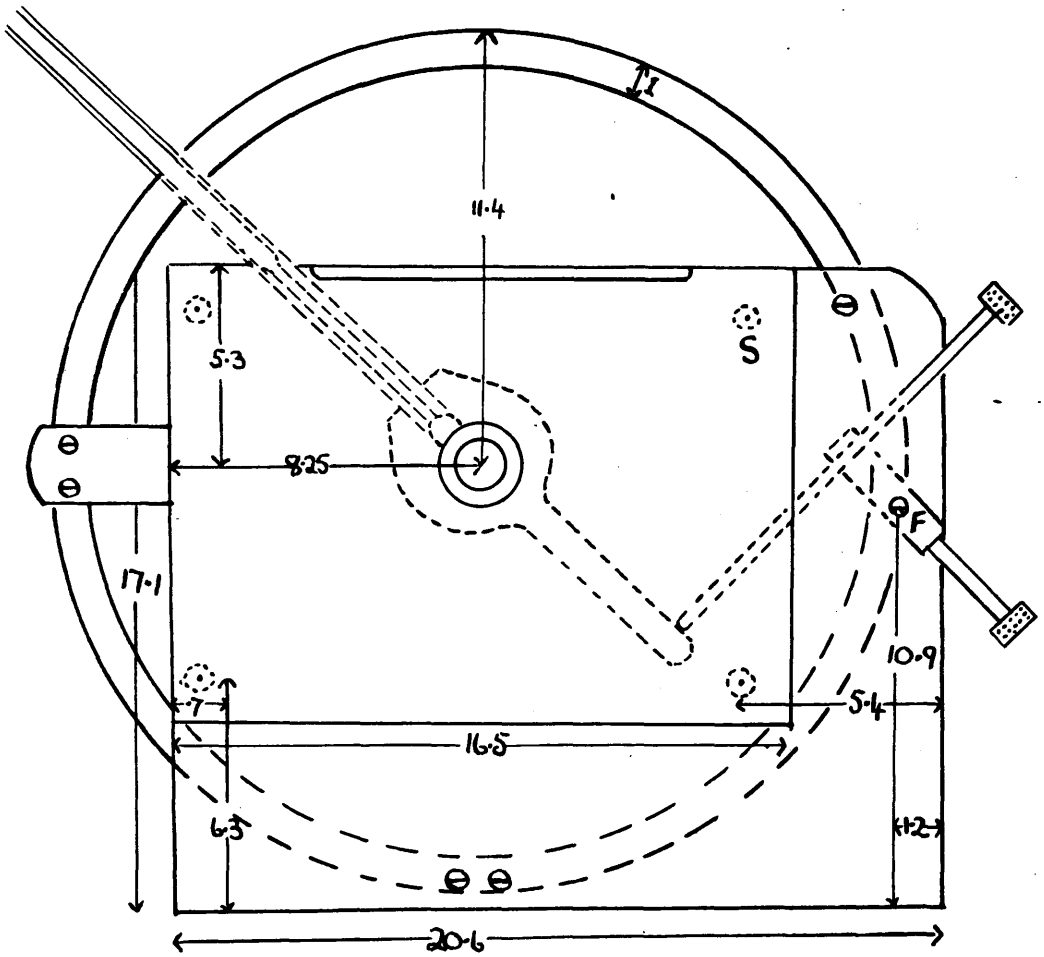
A square-faced Glazebrook analyser, mounted in a flanged brass tube, is inserted into a tube (a) capable

of rotating between the central aperture of a circular brass plate (carrying a fixed vernier engraved in white metal and reading to 0.01°) and a hole cut in a rectangular plate held to the circle by distance pieces (six). Holes drilled in the flange allow lever adjustment of the prism mounting. The rectangular plate, protected by a layer of cork (16.5cm. x 10.8cm.), is attached to the cell compartment by four 'captive' screws, while the circular plate is drilled and tapped to receive four screws from the photocell box. A narrow brass piece, soldered to the rectangular plate and recessed to support the lid for the cell compartment, ensures that the unit is light-tight.

In the original model (98), rotation of the prism was controlled by a thin brass segment screwed to the rotatable tube (a) and carrying a vernier. Repeated use, however, twisted the segment and the scale and vernier gradually separated. The following, more stable, arrangement was then adopted.

A circular brass plate (carrying a scale engraved in white metal and reading to 0.2°) is supported on a narrow shoulder of a heavy plate (3mm. thick), drilled to fit the rotatable tube (a). Screws through a larger shoulder (8mm. long) on the side of the thick plate (b) nearest the monochromator are used to secure

# A

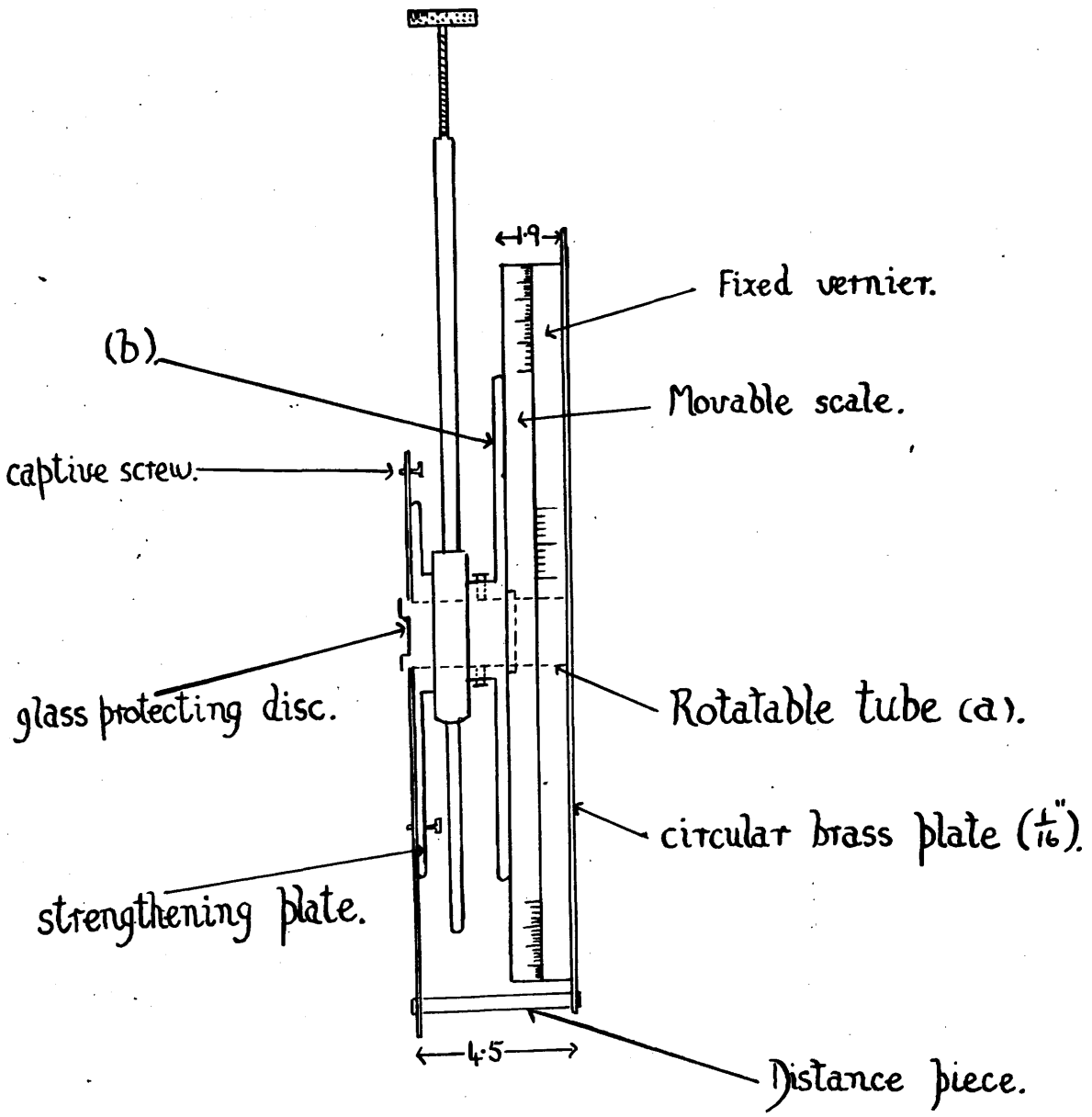



⊙ CAPTIVE SCREW.

⊖ DISTANCE PIECE.

scale: half actual in cm.

B




scale : half actual in cm.

the scale unit to (a). Rotation of the scale and prism is controlled by a cam-shaped brass block (9mm. thick) into which is screwed a long arm. A small half-moon shaped piece cut out of the block is driven against (a) by a steel rod actuated by a screw threaded into the arm. The block can rotate freely when the screw is unlocked. Lateral displacement of the half-moon is prevented by the shoulders both on the scale unit and on a strengthening disc screwed to the rectangular plate. Fine adjustment of the rotating arm is controlled by a long screw fixed to distance piece F (diagram A). This can only operate when the arm is in the 'active' position as shown. The scale is engraved so that clockwise rotation (i.e. positive optical rotation) brings increasing numbers (0° - 360°) into the field of an eyepiece attached to the plate carrying the vernier. New observation cells were constructed by drilling two holes (1cm. diameter) in a brass block of accurately known length (diagram C). The projection of the flange on the prism tube into the cell compartment limits the maximum length of cell to 2.5cm. Glass covering discs are secured to the brass by seccotine. The two filling holes are sealed with

tapered, carborundum ground, brass plugs.

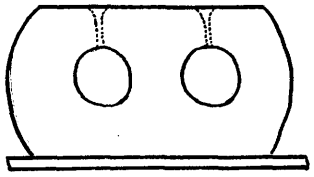


Diagram C

The polariser and analyser are adjusted visually so that, when they are crossed, the scale reads approximately 0°. The photoelectric zero is found directly by the 'method of symmetrical angles' (99, 100) in the following way:

(i) Place cell containing solvent in the light beam.

(ii) Turn transmission to 100 per cent.

(iii) Set the wavelength scale to the desired value.

(iv) Rotate the analyser to a fixed stop at -40° (320°). This is found to be the most convenient (mechanically) 'half-shadow angle'. The fixed stop (S) (diagram A) is a captive screw on the rectangular plate. With the scale reading -40° (320°), the rotating arm is unlocked, brought to rest against (S) and then re-locked.

(v) Expose the photocell and adjust the slit-width to give balance.

(vi) Rotate the analyser clockwise (by means of the arm and fine adjustment) through about 80° to a position $\theta_o$ to restore balance. The zero is then $\frac{1}{2}[\theta_o + (-40)]$.

Rotations are determined in a similar way:

(i') Place cell containing solution in the light beam.

(ii') Adjust transmission scale. If the solution is transparent the scale is left at 100 per cent; but if selective absorption occurs it may be necessary to select a smaller value to prevent the slit-width becoming too large.

Operations (iii'), (iv'), (v') and (vi') are carried out as for (iii), (iv), (v) and (vi). If, in (vi'), the analyser scale reads $\theta$, the rotation $\alpha$ is given by

$$\alpha = \tfrac{1}{2}[\theta + (-40)] - \tfrac{1}{2}[\theta_o + (-40)]$$

$$= \tfrac{1}{2}\theta - 20 - \tfrac{1}{2}\theta_o + 20$$

i.e. $\alpha = \tfrac{1}{2}(\theta - \theta_o)$.

The adjustment and reliability of the polarimeter were tested by a comparison of the rotations of an ethanolic solution of d-camphor determined in the same brass cell with a Hilger triple-field polarimeter. The results for this are set out in Table XXI. The rotation values obtained with the red-sensitive photocell ($P_\alpha$) were in good agreement with those

TABLE XXI

Comparison of the rotations of d-camphor determined visually and photoelectrically

Concentration, c = 5.0069g./50ml. absolute ethanol

l = 0.25dm. : half-shadow angle $\simeq 5°$ on visual polarimeter

Fixed stop on photoelectric polarimeter at -40°

Visual setting of extinction position of photoelectric polarimeter carried out at 540mμ.

Constant slits used with visual polarimeter.

Circular stops on each face of polarising prism.

Photoelectric zero taken at each wavelength.

$\vee_\alpha$ = visual rotations : $P_\alpha$ = photoelectric rotations

| λ(mμ) | $\vee_\alpha$ | $P_\alpha$ | Unicam slit mm. | Photo-cell | % $\Delta\alpha$ on $\vee_\alpha$ |
|---|---|---|---|---|---|
| 500 | +1.92 | +1.99 | 0.08 | Blue | + 3.6 |
| 520 | +1.63 | +1.75 | " | " | + 7.4 |
| 540 | +1.45 | +1.51 | " | | + 4.1 |
| 560 | +1.30 | +1.35 | " | " | + 3.8 |
| 580 | +1.19 | +1.23 | " | " | + 3.3 |
| 600 | +1.10 | +1.11 | 0.12 | " | + 0.9 |
| 620 | +1.00 | - | - | - | - |
| 640 | +0.89 | +0.89 | 0.12 | Red | 0.0 |
| 660 | +0.82 | +0.81 | 0.10 | " | - 1.2 |
| 680 | +0.76 | +0.74 | 0.08 | " | - 2.6 |
| | | | | | Aver. = + 2.1 |

determined visually ($V_\alpha$) over the same wavelength range. The discrepancies between $V_\alpha$ and $P_\alpha$ were greater and of opposite sign when the blue-sensitive photocell was used. This emphasised the difficulties encountered in the measurement of the intensity of polarised light with vacuum photocells, whose response to this type of light can be anisotropic (92). The instrument, however, was designed to measure the rotations of compounds whose absorption maxima are situated in the range covered by the 'red' cell.

The optical properties of β-caryophyllene nitrosite (101) - a pale blue, highly crystalline compound with maximum absorption at about 680mμ. - were investigated by Mitchell (102), who traced the curve of rotatory dispersion to the long-wave limits of visual polarimetry, that is, to about 700mμ. This work revealed one half of an extremely well developed Cotton effect with large positive rotations on the short-wave side of λmax. The complete curve of rotatory dispersion of (-)-β-caryophyllene nitrosite was successfully determined with the photoelectric polarimeter (Table XXII; Graph XVII). The characteristics of a benzene solution of the nitrosite are

$$[\alpha]_{625} = +1794^\circ \quad ; \quad [\alpha]_{735} = -2009^\circ$$

$$[\alpha] \simeq 0^\circ \text{ at } 680m\mu$$

TABLE XXII

Rotatory Dispersion of (-)-β-caryophyllene nitrosite

Concentration, c = 1.5280g./100ml. benzene (AnalaR)

l = 0.1dm. brass block

Percentage transmission = 60

Fixed stop at -40° (i.e. 320°)

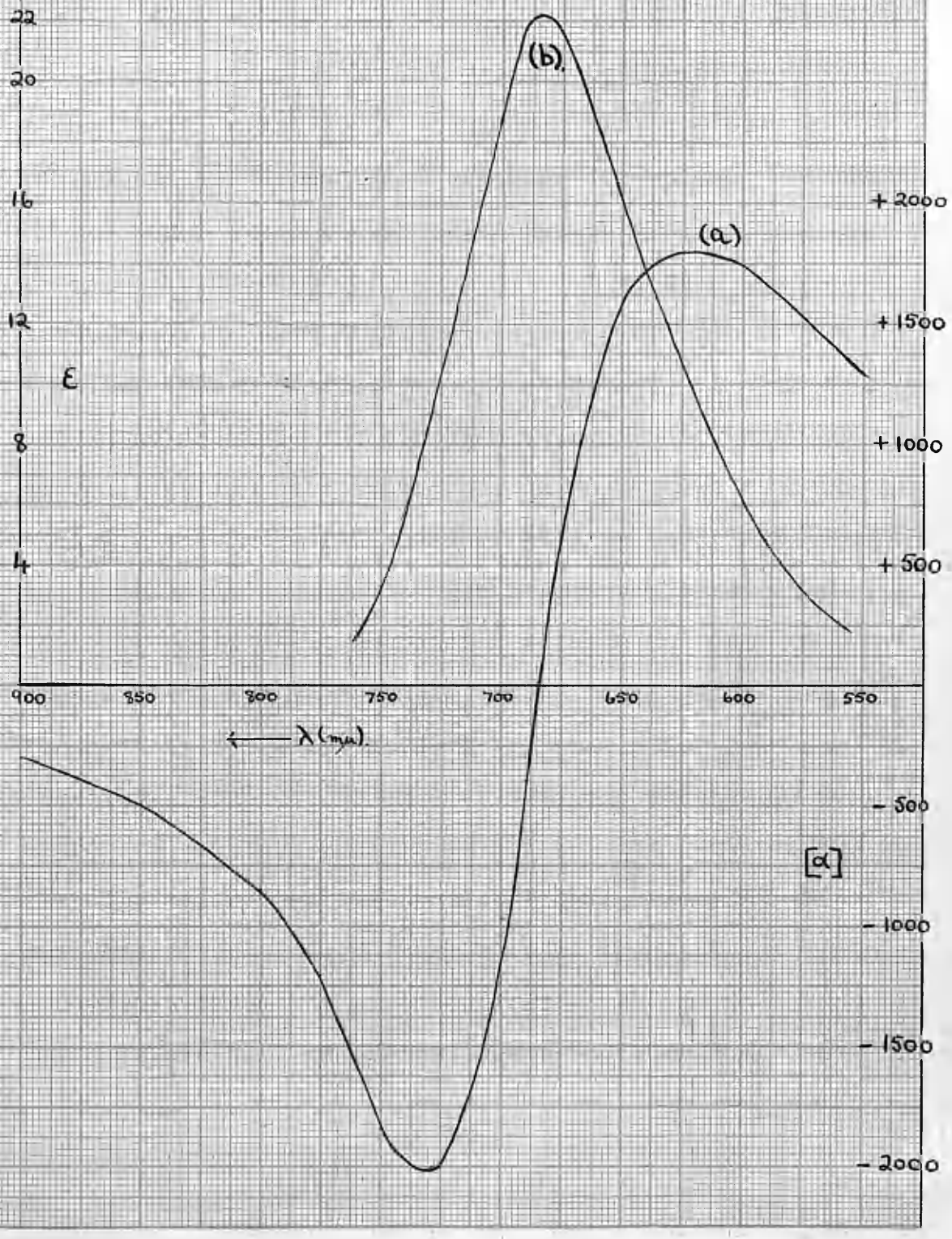
| λ(mμ) | α | [α] |
|---|---|---|
| 500 | +1.47* | + 962 |
| 550 | +1.93* | +1293 |
| 580 | +2.40* | +1571 |
| 600 | +2.67 | +1748 |
| 625 | +2.74 | +1794 |
| 650 | +2.42 | +1584 |
| 675 | +0.94 | + 615 |
| 680 | +0.41 | + 268 |
| 690 | -0.61 | - 400 |
| 700 | -1.96 | -1283 |
| 725 | -3.05 | -1996 |
| 735 | -3.07 | -2009 |
| 750 | -2.82 | -1846 |
| 775 | -1.84 | -1204 |
| 800 | -1.30 | - 851 |
| 850 | -0.76 | - 498 |
| 900 | -0.49 | - 303 |

* Visual readings

# Graph XVII.

## (-)-β-Caryophyllene Nitrosite.

(a) Rotatory Dispersion (b) Absorption Spectrum.



The mathematical analysis of the rotatory dispersion by the methods of Kuhn and Braun (103) and of Lowry and Hudson, to give the contribution of the nitroso group to the optical rotation in the visible spectrum, required a knowledge of the positions and intensities of the components of the curve of circular dichroism. Mitchell, by placing a quarter-wave plate (capable of a 90° rotation) between the polarising unit used in the polarimeter and the observation cell, was able to adapt a Unicam spectrophotometer to measure log $I_r/I_l$ directly and hence evaluate the circular dichroism in terms of $(\varepsilon_l - \varepsilon_r)$ (97). The instrument was set first to 100% transmission for left-handed circularly polarised light in the case of a compound with negative ellipticity. The $\lambda/4$-plate was then rotated through 90° when right-handed light was transmitted. The 'null-point' was restored by rotating the density scale which read log $I_l/I_r$ directly. The values of $-(\varepsilon_l - \varepsilon_r)$ for β-caryophyllene nitrosite obtained by this method are set out in Table XXIII. Although the red-active photocell gave values of the anisotropy factor (g) of the correct order of magnitude and with a constancy expected from curves of this type, the complete lack of correspondence between 'red' and 'blue'

TABLE XXIII

Photoelectric determination (vacuum photocells) of the circular dichroism of (-)-β-caryophyllene nitrosite

Concentration, c = 0.0400g./10ml. Thiophen-free, sodium-dried benzene

t = 2.5cm. Brass cell. M = 0.01429

Maximum slit = 0.1mm.

| Cell | $\lambda(m\mu)$ | $\log \frac{I_1}{I_2}$ | $-(\varepsilon_1 - \varepsilon_2)$ | $\varepsilon$ | g |
|---|---|---|---|---|---|
| Blue | 590 | 0.0249 | 0.697 | 4.82 | 0.15 |
| " | 600 | 0.032 | 0.896 | 6.14 | 0.15 |
| Red | 600 | 0.0155 | 0.43 | - | 0.07 |
| Blue | 610 | 0.039 | 1.09 | 7.86 | 0.14 |
| Red | 610 | 0.0225 | 0.63 | - | 0.08 |
| Blue | 620 | 0.046 | 1.29 | 9.76 | 0.13 |
| Red | 620 | 0.030 | 0.84 | - | 0.086 |
| " | 630 | 0.0375 | 1.05 | 11.71 | 0.09 |
| " | 640 | 0.0464 | 1.29 | 13.77 | 0.095 |
| " | 650 | 0.0575 | 1.61 | 16.12 | 0.10 |
| " | 660 | 0.0705 | 1.97 | 18.41 | 0.11 |
| " | 670 | 0.0856 | 2.39 | 20.78 | 0.12 |
| " | 680 | 0.091 | 2.55 | 22.25 | 0.12 |
| " | 685 | 0.092 | 2.58 | 22.25 | 0.12 |
| " | 690 | 0.090 | 2.52 | 21.75 | 0.12 |
| " | 700 | 0.079 | 2.21 | 18.96 | 0.12 |
| " | 710 | 0.0646 | 1.81 | 15.39 | 0.12 |
| " | 720 | 0.049 | 1.37 | 12.08 | 0.11 |
| " | 730 | 0.0355 | 0.99 | 8.59 | 0.12 |

values in the range 600-620mμ revealed once more the large differences in the response of these cells to different types of light. This difficulty was overcome by replacing the vacuum photocells with a barrier-layer photronic cell, sensitive between 480mμ and 700mμ and with maximum sensitivity at 600-610mμ, the region of minimum sensitivity on both vacuum cells. The barrier-layer cell, enclosed in a light-tight box screwed to the cell compartment of the Unicam instrument, was connected by very short leads to a two-metre reflecting galvanometer. The values of $+(\varepsilon_r - \varepsilon_l)$ and 'g' obtained by this method are shown in Table XXIV. These agree well with the values given in Table XXIII in the wavelength range 640-685mμ, and the discrepancies at 600-620mμ have been eliminated. Graph XVIII illustrates the curves of circular dichroism and anisotropy factor obtained by a combination of values between 560 and 650mμ (Table XXIV) and those between 660 and 760mμ (Table XXIII). The lack of precision in these measurements and the small degree of asymmetry of the curve of circular dichroism made unfeasible the analysis of this curve into its components by methods of trial and error using Gaussian equations of the type

$$(\varepsilon_l - \varepsilon_r) = (\varepsilon_l - \varepsilon_r)_{max.} \frac{\lambda_o}{\lambda} e^{-\left(\frac{\lambda-\lambda_o}{\Theta}\right)^2}$$

TABLE XXIV

Photoelectric determination (barrier-layer cell) of the circular dichroism of (-)-β-caryophyllene nitrosite

Concentration, c = 0.0242g./5ml. Thiopen-free, sodium-dried benzene

t = 2.5cm. Brass cell. M = 0.01769

Slit constant at 0.35mm.

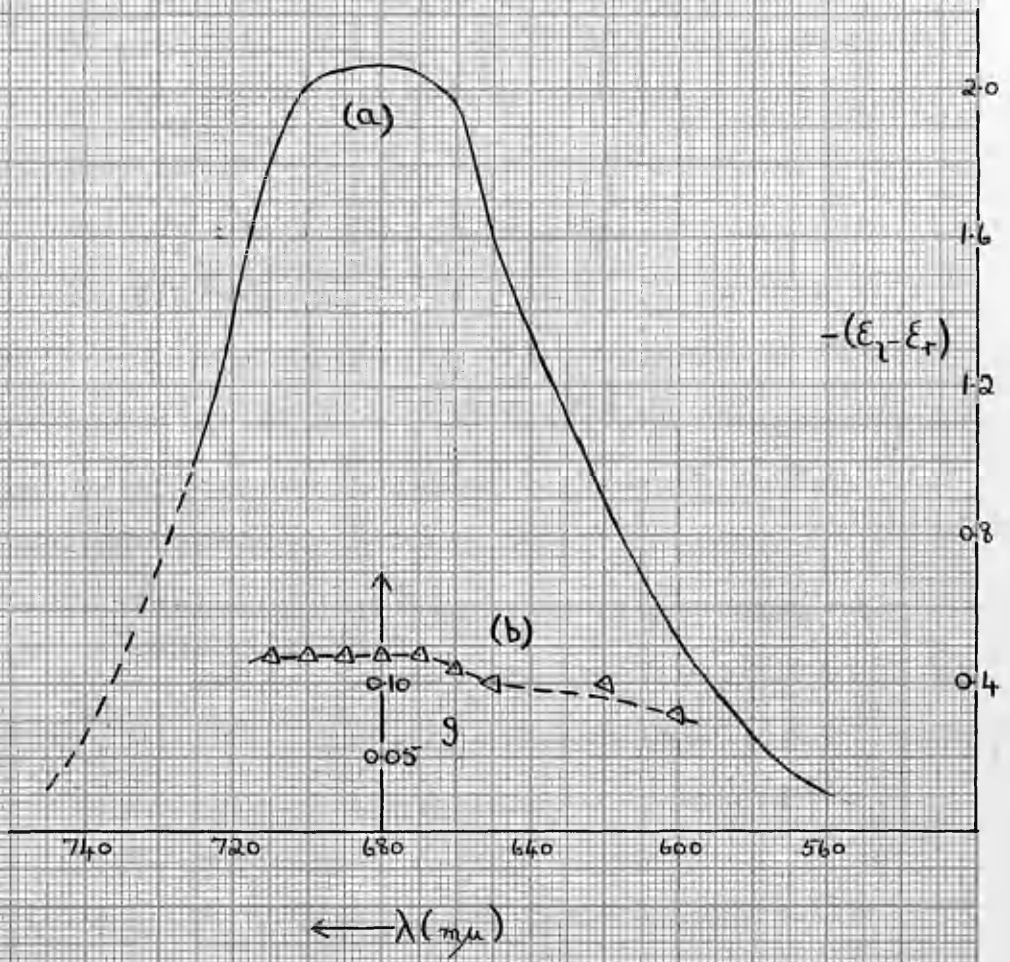
| λ(mu) | Deflecn. for left light | Deflecn. for right light | $-(\varepsilon_l - \varepsilon_r)$ | g |
|---|---|---|---|---|
| 560 | 24.25 | 24.0 | 0.102 | 0.049 |
| 570 | 25.2 | 24.8 | 0.156 | 0.056 |
| 580 | 25.5 | 24.85 | 0.251 | 0.068 |
| 590 | 24.8 | 23.9 | 0.364 | 0.076 |
| 600 | 22.8 | 21.7 | 0.484 | 0.079 |
| 605 | 21.6 | 20.3 | 0.611 | 0.088 |
| 610 | 20.1 | 18.7 | 0.710 | 0.090 |
| 615 | 18.35 | 16.9 | 0.809 | 0.092 |
| 620 | 16.8 | 15.3 | 0.918 | 0.098 |
| 625 | 15.2 | 13.7 | 1.02 | 0.096 |
| 630 | 13.6 | 12.1 | 1.15 | 0.098 |
| 635 | 11.9 | 10.5 | 1.23 | 0.097 |
| 640 | 10.4 | 9.0 | 1.42 | 0.10 |
| 645 | 8.4 | 7.2 | 1.52 | 0.10 |
| 650 | 7.1 | 6.0 | 1.65 | 0.10 |
| 660 | 4.8 | 3.9 | 2.04 | 0.11 |
| 670 | 2.9 | 2.3 | 2.28 | 0.11 |
| 680 | 1.8 | 1.4 | 2.47 | 0.11 |
| 685 | 1.5 | 1.15 | 2.61 | 0.12 |

# Graph XVIII

## (-)-β-Caryophyllene Nitrosite.

## Photoelectric Determination of

(a) Circular Dichroism (b) Anisotropy Factors.



It was thought that the absorption spectrum of the nitrosite, which could be determined with greater overall accuracy, might be more easily resolved into its components. Moreover, the partial rotations due to a band can, in the absence of dichroism measurements, be deduced from absorption data by assuming (a) that $\varepsilon_l - \varepsilon_r / \varepsilon \propto \nu$ and (b) that the dichroism curve has the same maximum and half-width as the absorption band. This procedure was adopted by Kuhn in the analysis of the partial rotations due to the azido group in the dimethylamide of α-azidopropionic acid (44). The spectrum of (-)-β-caryophyllene nitrosite (Table XXIV ; Graph XVII), unlike those of the monomeric chloro-nitroso compounds, showed no characteristic shoulder on the short-wave side of λ max. and was only slightly asymmetrical, the values of $\lambda_{\varepsilon = \frac{\varepsilon_{max}}{2}} - \lambda$ max. being 39.9 and 55.3 . Change of solvent had no effect on λ max. or the general shape of the absorption envelope. The values of ε max. decreased with increasing dielectric constant of the solvent.

| Solvent | ε max. | Dielectric constant* |
|---|---|---|
| Benzene | 22.25 | 2.28 at 20°C |
| Acetone | 19.48 | 25.7 " " |
| Ethanol | 19.54 | 21.4 " " |
| Acetonitrile | 19.29 | 38.8 " " |

* International Critical Tables. Vol.VI.

TABLE XXV

Absorption Spectrum of (-)-β-caryophyllene nitrosite in benzene

Concentration, c = 0.0502g./5ml. Thiopen-free, sodium-dried benzene

M = 0.03586 t = 1cm. Max. slit = 0.06mm.

| λ(mu) | $\log {}^{I_o}/_{I}$ | ε |
|---|---|---|
| 560 | 0.075 | 2.09 |
| 570 | 0.099 | 2.79 |
| 580 | 0.132 | 3.68 |
| 590 | 0.173 | 4.82 |
| 600 | 0.220 | 6.14 |
| 605 | 0.248 | 6.92 |
| 610 | 0.282 | 7.86 |
| 615 | 0.316 | 8.81 |
| 620 | 0.350 | 9.76 |
| 625 | 0.381 | 10.6 |
| 630 | 0.420 | 11.7 |
| 635 | 0.455 | 12.7 |
| 640 | 0.494 | 13.8 |
| 645 | 0.533 | 14.9 |
| 650 | 0.578 | 16.1 |
| 655 | 0.618 | 17.2 |
| 660 | 0.660 | 18.4 |
| 665 | 0.706 | 19.7 |
| 670 | 0.745 | 20.8 |
| 675 | 0.778 | 21.7 |
| 680 | 0.798 | 22.25 |
| 685 | 0.798 | 22.25 |
| 690 | 0.780 | 21.8 |
| 695 | 0.740 | 20.6 |
| 700 | 0.680 | 18.96 |
| 705 | 0.617 | 17.2 |
| 710 | 0.552 | 15.39 |
| 715 | 0.492 | 13.7 |
| 720 | 0.433 | 12.1 |
| 725 | 0.368 | 10.3 |
| 730 | 0.308 | 8.59 |
| 735 | 0.253 | 7.06 |
| 740 | 0.200 | 5.58 |
| 745 | 0.158 | 4.41 |
| 750 | 0.117 | 3.26 |
| 755 | 0.086 | 2.39 |
| 760 | 0.063 | 1.76 |
| 765 | 0.042 | 1.17 |
| 770 | 0.029 | 0.081 |

The analysis of the structureless spectrum of the nitrosite was attempted using the statistical method developed by Pearson in his 'Contribution to the Mathematical Theory of Evolution' (104). This method allows the dissection of asymmetrical frequency curves into two unique components. Since absorption curves have the same mathematical form, it was possible to apply the method to the problem. On a wavelength scale, 500 mμ was selected as the new origin and the abscissae range covered by the spectrum (ethanol : c = 0.0395g./10ml.:t = 2.5cm) divided into thirty units, each corresponding to 10 mμ (1 unit = $^{4}/_{10}$"). The ordinates were maintained as molecular extinction coefficients (moles.$^{-1}$ cm$^{-1}$) (1 unit = $\frac{1}{2}$"). This eliminated the introduction of new errors by a change in the accuracy of the plot. The curve was thus defined by the following values of x and y :-

| x | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| y | 0 | 0.142 | 0.281 | 0.488 | 0.737 | 1.15 | 1.67 | 2.43 | 3.23 | 4.23 | 5.52 |

| x | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| y | 7.03 | 8.74 | 10.47 | 12.30 | 14.12 | 16.11 | 18.44 | 19.54 | 18.94 | 16.39 |

| x | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|
| y | 13.19 | 9.90 | 6.76 | 4.11 | 2.27 | 1.17 | 0.539 | 0.227 | 0.113 | 0.057 |

The first five moment coefficients about the vertical through the origin were calculated as follows, being the nth. moment coefficient,

$$u_n^1 = \frac{1^n y_1 + 2^n y_2 + \ldots\ldots\ldots 30^n y_{30}}{\text{Area}}$$

The area under the curve was found to be 198.06 sq. units, whence

| | | | |
|---|---|---|---|
| $u_1^1$ | = = | 16.8216 | $u_1$ = 0 |
| $u_2^1$ | = | 300.1322 | $u_2$ = + 17.1660 |
| $u_3^1$ | = | 5,627.2196 | $u_3$ = + 0.9966 |
| $u_4^1$ | = | 109,682.934 | $u_4$ = + 401.5238 |
| $u_5^1$ | = | 2,207,992.204 | $u_5$ = +7,397.840 |

$u_1^1$ gave the distance of the centroid vertical from the origin and the moment coefficients ($u_2$,$u_3$ etc.) about this line were calculated from the following equations:-

$$u_2 = u_2^1 - q^2$$

$$u_3 = u_3^1 - 3q\,u_2^1 + 2q^3$$

$$u_4 = u_4^1 - 4q\,u_3^1 + 6q^2 u_2^1 - 3q^4$$

$$u_5 = u_5^1 - 5q\,u_4^1 + 10q^2 u_3^1 - 10q^3 u_2^1 + 4q^5$$

These values were then used to determine, after considerable labour, the coefficients in Pearson's 'fundamental nonic equation', which in this case was found to be:-

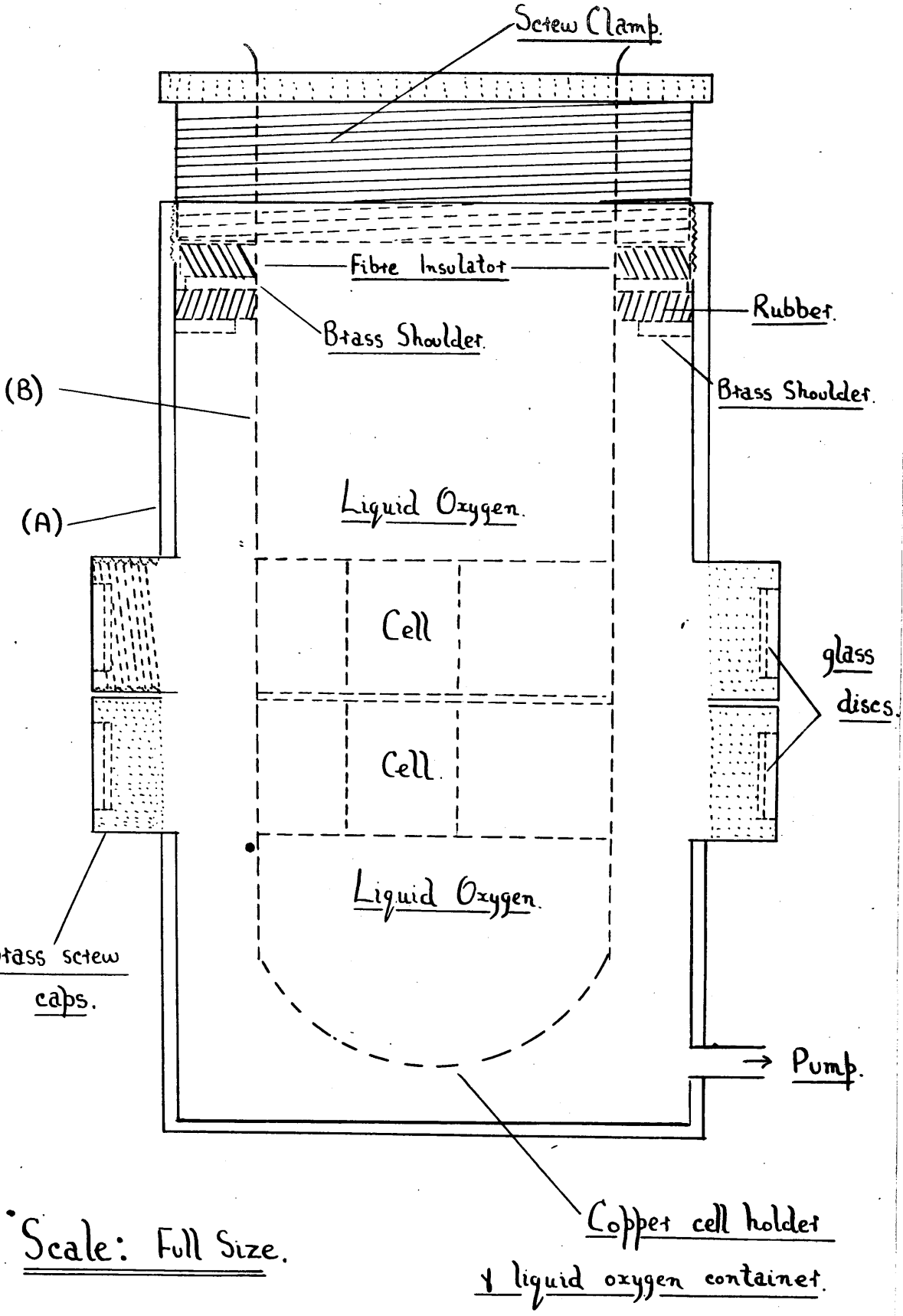
$$x^9 - 16.8872x^7 + 0.001489x^6 + 89.4597x^5 - 391.7845x^4$$
$$- 110.7256x^3 - 0.06284x^2 + 0.00001904x - 0.9798 \times 10^{-9} = 0.$$

A real negative root of this equation was found by Horner's method of successive approximation to be situated at $-2.6608$. This gave values of $\gamma_1$ and $\gamma_2$, the positions of the centroid verticals of the components, at $+0.1655$ and $-16.0464$. The latter value was obviously outwith the range covered by the absorption spectrum and was therefore discarded. Refinement of the analysis failed to yield a satisfactory solution, the roots obtained giving one real and one imaginary value of $\gamma$.

The failure of this method may have been due to the presence of more than two components - in which case the Pearson analysis is inapplicable - or to the fact that the method is too exact to cope with curves of slight asymmetry. Again, as pointed out by Pearson, a small value of $u_3$ indicates approximate symmetry. The value calculated in this case ($u_3 = +0.9966$) supported this conclusion.

Absorption measurements at low temperature were then undertaken in an attempt to resolve the spectrum of β-caryophyllene nitrosite. The sharpness of low-temperature absorption curves depends largely upon the limitation of the vibrations and rotations of small energy in the excited state. The successful resolution of the spectrum of a monomeric bromo-nitroso compound by Lewis and Kasha (27) during an investigation of the triplet-state theory of n -- $\pi^*$ transitions in the NO group, made this method of approach to the analysis of the spectrum of the nitrosite appear most promising.

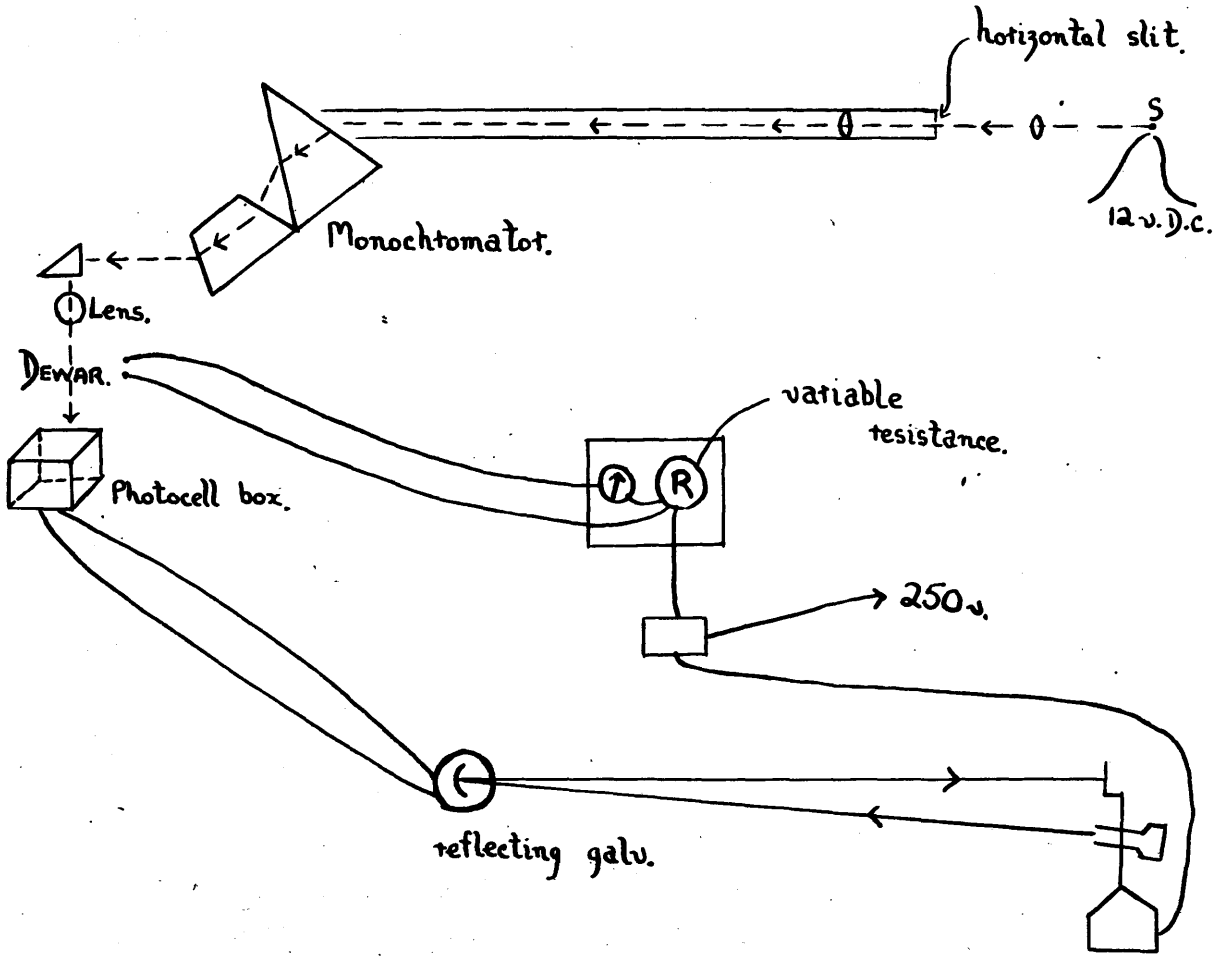
An all-metal Dewar (⅛" brass), kindly loaned by Dr E. Clar, was used for these measurements (see Diagram). ). The outer casing (A) of the Dewar was lagged with asbestos carrying a heating coil attached to a variable resistance (Variac) and an ammeter. The heater prevented condensation of atmospheric moisture on the observation windows. The inner copper vessel (B), which housed the absorption cells and could be filled with liquid oxygen, was thermally and electrically insulated from the outer casing by a rubber collar wound round the upper part of the latter. Both vessels were held rigidly together by a screw clamp threaded to the top, inner surface of the brass cylinder.




Scale: Full Size.

The efficiency of this air-tight connection was maintained by a system of rubber and fibre washers, the former being in contact with the metal shoulder on (A) and the latter with a similar shoulder on (B). The glass absorption cells (2cm. Hilger) were sheathed in a threaded brass sleeve to which the brass caps holding the glass windows were screwed. In this work it was found more practicable to use a glass to glass contact with the rubber washer outermost. The optical system is illustrated pictorially overleaf. Light from a 12 volt, tungsten-coil lamp was focussed on the horizontal slit of a Winkel-Zeiss monochromator. The emergent beam was then refracted through 90° by a right-angled prism and refocussed on the absorption cells by a convex lens placed immediately in front of the prism. The light from the cells was received on a barrier-layer photronic cell enclosed in a light tight box and connected to a two-metre reflecting galvanometer (Tinsley). The horizontal width of the beam entering the absorption cells was controlled by a triangular wedge inserted in front of the entrance slit of the monochromator. It should be noted that the space formed in the cells by low-temperature contraction of the

# Low-Temperature Optical System.



solution did not interfere with the transmission of the beam through the cells. The difficulty of raising and lowering the heavy Dewar to bring solvent and solution alternately (and accurately) into the beam was overcome by placing the vessel on a tray secured to the top of the barrel of a car jack. Two vertical rods screwed to the tray and the base of the jack carried adjustable stops and permitted smooth positioning of the cells in the beam.

Procedure:

(a) The filled cells were placed in (B) which was then secured to the outer vessel (A) by means of a screw clamp. This was facilitated by a heavy 'pin-key' cut to fit the clamp. The solvent used was E. P. A. i.e., a mixture of ether, isopentane (B. D. H. : b.p. 27-31°C) and ethanol in the ratio 5:5:2 which 'set' to a rigid glass at low temperatures.

(b) The liquid oxygen was then poured into (B). Evacuation of the Dewar with a two-stage oil pump was commenced a few minutes after the addition of the oxygen. This eliminated loss of solvent by vacuum evaporation. The cells, although surrounded by refrigerant, were not in contact with it.

(c) A slowly increasing voltage was then applied to the heating coil. When the apparatus had been thoroughly cooled it was found that a current of one ampere (at 170 volts) was sufficient to keep the outer windows free from moisture.

(d) A minimum cooling time of three quarters of an hour was allowed before measurements were undertaken.

(e) Variation in the photoelectric current due to the cascade of cold air over the outer windows was eliminated by placing a metal hood over (B).

(f) The monochromator slits and orientation of the Dewar were adjusted to give a deflection of about 50cm. when light of wavelength 600-610mu. was transmitted through the solvent.

(g) The low-temperature spectrum was then constructed from the values of the scale deflections recorded at each wavelength for light transmitted alternately through the solvent and solution. The shutter of the photocell box was closed after every second pair of readings and fresh liquid oxygen added to maintain the original level. Separation of the brass components of the cells at low temperature resulted in a small loss of liquid by leakage when the apparatus was allowed to warm to room temperature. The room temperature spectrum had therefore to be determined first.

The results of a typical experiment with (-)-β-caryophyllene nitrosite are given in Table XXVI and illustrated in Graphs XIX. The low-temperature spectrum showed some outstanding features. The development of two well defined shoulders on the short-wave side of $\lambda$max. indicated the presence of at least three components. The values of $\log {}^{I_o}/_{I}$ were greatly enhanced, those at 670mu, 615mu and 580 - 500mu. being almost twice those recorded at room temperature. A similar doubling of the intensity of absorption has been reported by Clar for the low-temperature spectrum of azulene in the red-region of the spectrum. (105, 106). Moreover, the fact that the long-wave limits of the envelope had narrowed considerably (decrease in $\log {}^{I_o}/_{I}$ ) while those at short-wave had broadened (increase in $\log {}^{I_o}/_{I}$ ) provided additional evidence of a short-wave component.

The mathematical analysis of the experimental low-temperature spectrum of β-caryophyllene nitrosite was carried out using the following equation.

$$\varepsilon = \varepsilon_{max.}\, e^{-\left(\frac{\lambda - \lambda_o}{\theta}\right)^2}$$

The positions of the maxima of the components and the wavelengths at which $\log {}^{I_o}/_{I}$ is half the maximum value were

TABLE XXVI

Absorption Spectrum of (-)-β-caryophyllene nitrosite at (a) room temperature and (b) low temperature, i.e. 90°K ca.

Concentration, c = 0.0499g./20ml. E.P.A. t = 2cm.

Monochromator slits:- Entrance = 0.9; Exit = 0.4

Pressure, p = 0.26mm.Hg. at low temperature only

| λ(mu) | $\log^{I_o/I} \times 10^2$ room temp. | $\log^{I_o/I} \times 10^2$ low temp. | λ(mu) | $\log^{I_o/I} \times 10^2$ room temp. | $\log^{I_o/I} \times 10^2$ low temp. |
|---|---|---|---|---|---|
| 500 | - | 7.08 | 630 | 22.8 | 43.5 |
| 510 | - | 8.29 | 635 | 24.9 | 45.2 |
| 520 | 1.55 | 9.06 | 640 | 27.1 | 48.7 |
| 530 | 2.08 | 9.17 | 645 | 29.8 | 53.9 |
| 540 | 2.69 | 10.1 | 650 | 31.8 | 60.8 |
| 550 | 3.78 | 11.8 | 655 | 33.6 | 65.9 |
| 560 | 5.15 | ? | 660 | 35.3 | 60.7? |
| 565 | 5.60 | 15.1 | 665 | 36.1 | 73.6 |
| 570 | 6.42 | 16.0 | 670 | 36.3 | 73.2 |
| 575 | 7.29 | 17.4 | 675 | 35.5 | 70.4 |
| 580 | ? | 18.2 | 680 | 33.4 | 64.1 |
| 585 | 9.57 | 19.1 | 685 | 30.5 | 55.3 |
| 590 | 10.2? | 22.4 | 690 | 26.7 | ? |
| 595 | 12.2 | 25.7 | 695 | 23.3 | 35.4 |
| 600 | 13.4 | 28.8 | 700 | 21.3 | 25.3 |
| 605 | 15.2 | 32.6 | 705 | - | 5.9 |
| 610 | 17.1 | 36.4 | 710 | 14.8 | 1.5 |
| 615 | 18.6 | 38.3 | 720 | 11.2 | - |
| 620 | 20.0 | 40.5 | 730 | 7.49 | - |
| 625 | 21.5 | 41.9 | 740 | 3.27 | - |
| | | | 750 | 2.04 | - |

Note:

1) No obvious loss of liquid material at low temperature.

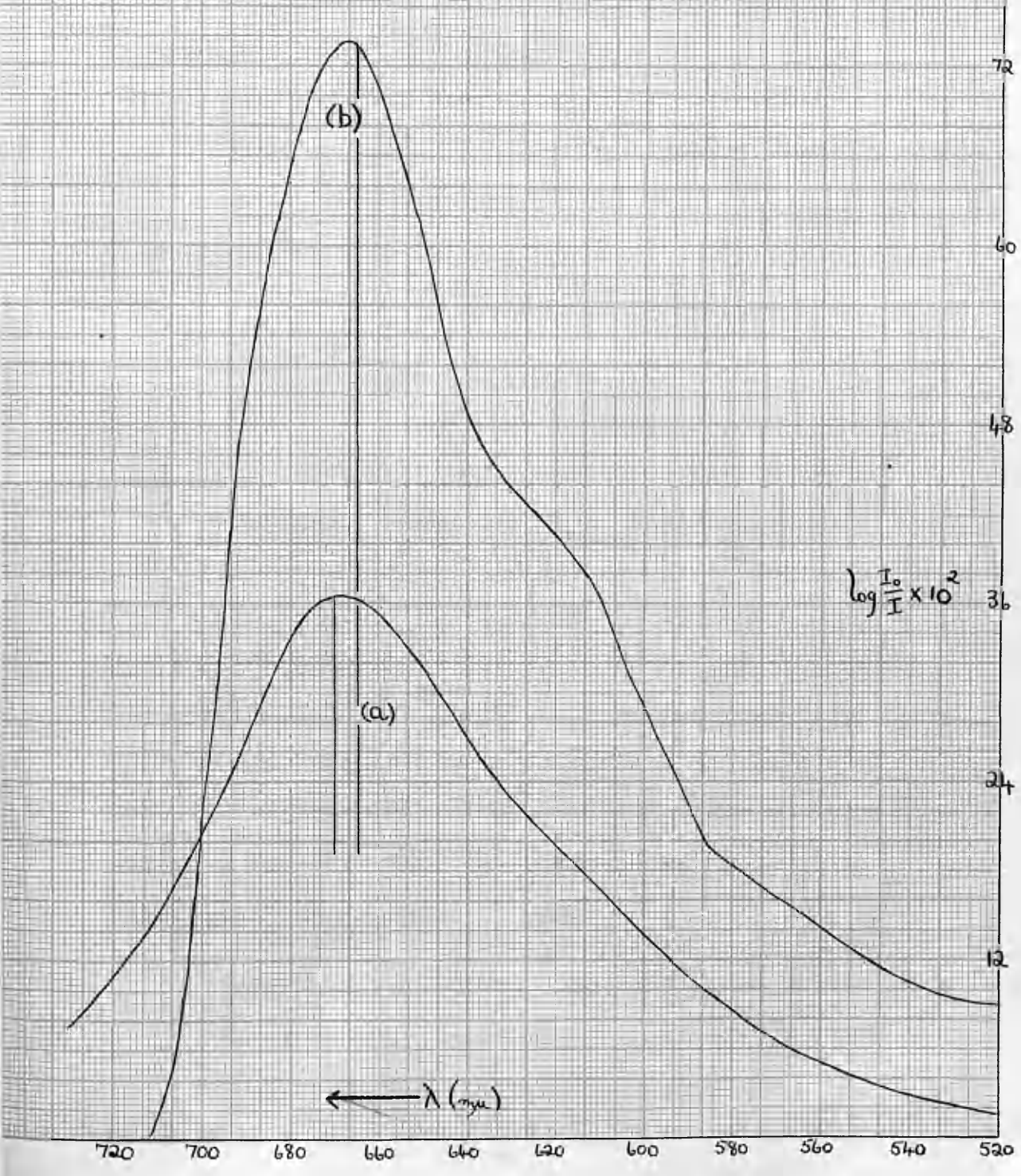
2) Scanned spectrum from 650-690mu with photocell continually exposed, first for solvent and then for solution. No fine structure at peak, cf. diisopropylbromonitrosomethane (27).

# Graph XIX.

## (−)-β-Caryophyllene Nitrosite

Absorption Spectrum at

(a) Room Temp. (b) Low Temp (≃ 90°K).



arbitrarily assumed and, by trial and error, the best fit to the observed curve obtained by summing the components. As expected from the shape of the curve, three such components were required.

Method. e.g. Large component.

Assume $\lambda_o = 6700$ where $\log {}^{I_o}/_{I}$ x $10^2 = 68.4$

and $\lambda = 6960$ " $\log {}^{I_o}/_{I_{max.}}$ x $10^2 = 34.2$

i.e. $\lambda - \lambda_o = 260.$

From the above equation

$$-\left(\frac{260}{\theta}\right)^2$$

$$34.2 = 68.4\ e$$

$$\therefore\ \theta = 312.3.$$

Substituting again in the equation we have

$$\text{Log } x = \log 68.4 - \left(\frac{D}{312.3}\right)^2\ 0.4343.$$

where D is the difference in wavelength between the maximum and a point on the curve where the absorption has a value x. For values of D 100, 200, 300, 400, 500 etc., x was calculated. The results are tabulated in Table XXVII(Graph XX). Similar calculations were required for the other two components.

First small component.

$\lambda_o = 6150$ where $\log {}^{I_o}/_{I}$ max. x$10^2 = 35.2$

$\lambda = 6450$ " $\log {}^{I_o}/_{I}$ x$10^2 = 17.6$

i.e. $\lambda - \lambda_o = 300$ and $\theta = 360.3.$

Second small component.

$\lambda_o$ = 5600 where $\log I_o/I$ max $\times 10^2$ = 11

$\lambda$ = 5770 " $\log I_o/I$ $\times 10^2$ = 5.5

i.e. $\lambda - \lambda_o$ = 170 and $\theta$ = 204.2

A small but definite displacement of the low-temperature spectrum towards the blue (also observed by Clar in the spectrum of azulene), vitiated the original idea of applying the above results to the calculation of the partial rotations due to the nitroso group in the rotatory dispersion determined at room temperature. However a preliminary analysis of the room-temperature spectrum was carried out using values of $\lambda_o$ for the components determined above. This revealed that the structureless spectrum could be represented as the sum of three components, that situated at shortest wavelengths being of extremely low intensity and with a large half-width value (below and Table XXVIII; Graph XXI).

Large component.

$\lambda_o$ = 6700 where $\log I_o/I$ max $\times 10^2$ = 33

and $\lambda$ = 7080 " $\log I_o/I$ $\times 10^2$ = 16.5

i.e. $\lambda - \lambda_o$ = 380 and $\theta$ = 456.4

First small component.

$\lambda_o$ = 6150 where $\log I_o/I$ max $\times 10^2$ = 10.6

and $\lambda$ = 6450 " $\log I_o/I$ $\times 10^2$ = 5.3

i.e. $\lambda - \lambda_o$ = 300 and $\theta$ = 360.3

Second small component.

$\lambda_o$ = 5600 where $\log I_o/I$ max $\times 10^2$ = 4.4

and $\lambda$ = 5980 " $\log I_o/I$ $\times 10^2$ = 2.2

i.e. $\lambda - \lambda_o$ = 380 and $\theta$ = 456.4

As shown in Graph XXI, a better fit to the experimental curve would be obtained by choosing greater values of i.e. by displacement towards the value of $\lambda$ max at room temperature. An indication of the resolution of the components is given by a comparison of the half-width values ($\lambda - \lambda_o$) of the components at the two temperatures.

| Component | Low Temp. ($\lambda - \lambda_o$) | Room Temp. ($\lambda - \lambda_o$) |
|---|---|---|
| 1 | 260 | 380 |
| 2 | 300 | 300 |
| 3 | 170 | 380 |

It would therefore appear that the failure of the Pearson analysis was due to the presence of this third, rather diffuse component.

The measurement of the rotatory dispersion or circular dichroism of active solutions at low-temperature presents considerable experimental difficulties. e.g.

(1) The strains set up at low temperature would result in the development of considerable anisotropy.in the rigid, glass-like solvent (E. P. A.).

(2) A similar optical anisotropy, arising from the strain

TABLE XXVII

Analysis of Low-Temperature Spectrum of β-caryophyllene nitrosite

(a) Large component:- $\lambda_o = 6700$

| λ(A) | $\log \frac{I_o}{I} \times 10^2$ |
|---|---|
| 6800, 6600 | 61.8 |
| 6900, 6500 | 45.4 |
| 7000, 6400 | 27.2 |
| 7100, 6300 | 13.3 |
| 7200, 6200 | 5.3 |

(b) First small component:- $\lambda_o = 6150$

| λ(A) | $\log \frac{I_o}{I} \times 10^2$ |
|---|---|
| 6250, 6050 | 32.6 |
| 6350, 5950 | 25.9 |
| 6450, 5850 | 17.6 |
| 6550, 5750 | 10.3 |
| 6650, 5650 | 5.1 |

(c) Second small component:- $\lambda_o = 5600$

| λ(A) | $\log \frac{I_o}{I} \times 10^2$ |
|---|---|
| 5700, 5500 | 8.7 |
| 5800, 5400 | 4.2 |
| 5900, 5300 | 1.3 |
| 6000, 5200 | 0.24 |

Graph XX.

(-)-β-Caryophyllene Nitrosite.

Analysis of Low-Temperature Absorption Spectrum.

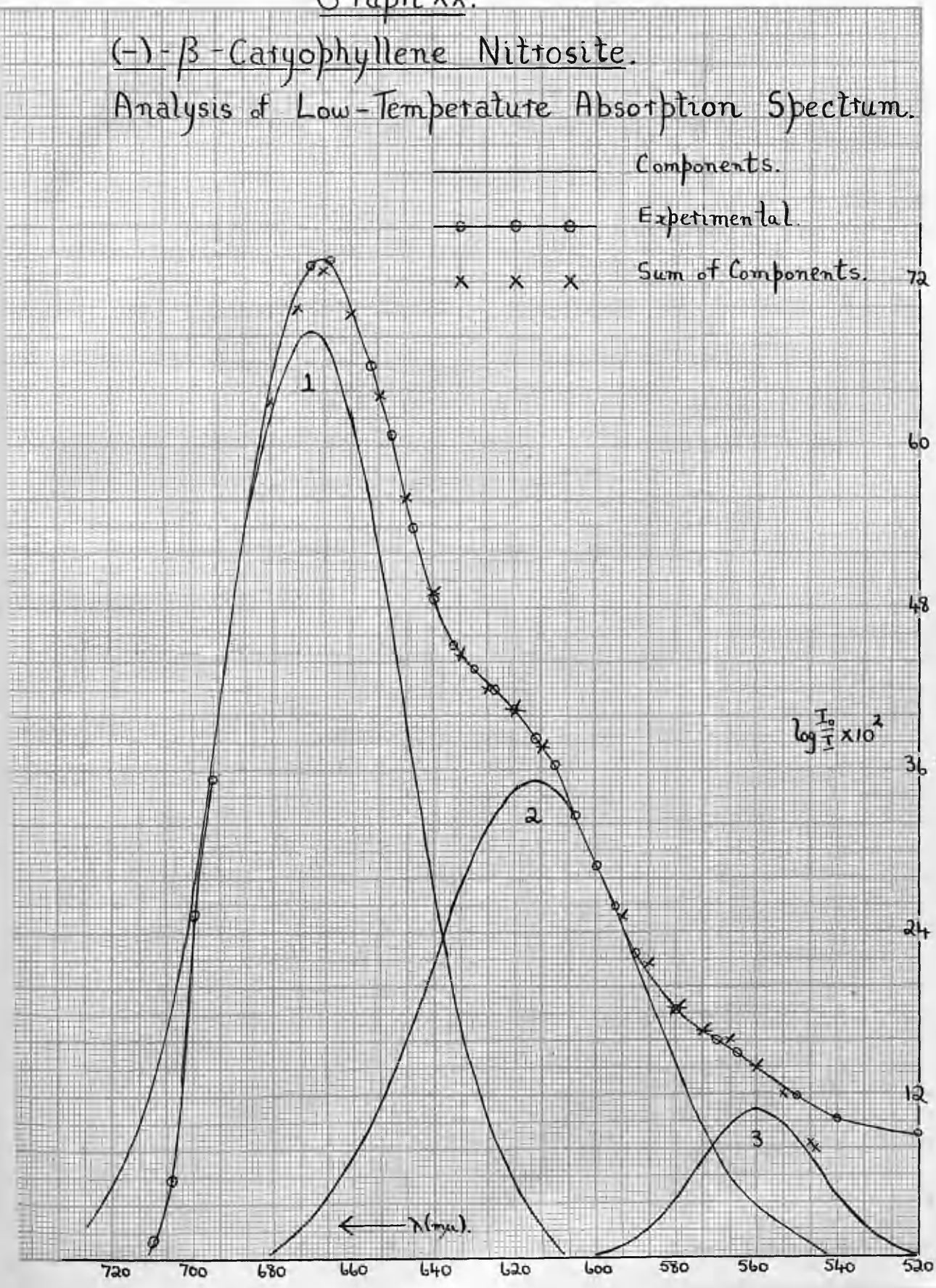


TABLE XXVIII

Preliminary Analysis of Room-Temperature Spectrum of β-caryophyllene nitrosite using values of $\lambda_o$ given in Table XXVII

(a) Large component:-

| λ(A) | $\log I_o/I \times 10^2$ |
|---|---|
| 6800, 6600 | 31.5 |
| 6900, 6500 | 27.2 |
| 7000, 6400 | 21.4 |
| 7100, 6300 | 15.3 |
| 7200, 6200 | 9.9 |
| 7300, 6100 | 5.9 |
| 7400, 6000 | 3.2 |

(b) First small component:-

| λ(A) | $\log I_o/I \times 10^2$ |
|---|---|
| 6050, 6250 | 9.8 |
| 5950, 6350 | 7.8 |
| 5850, 6450 | 5.3 |
| 5750, 6550 | 3.1 |
| 5650, 6650 | 1.6 |

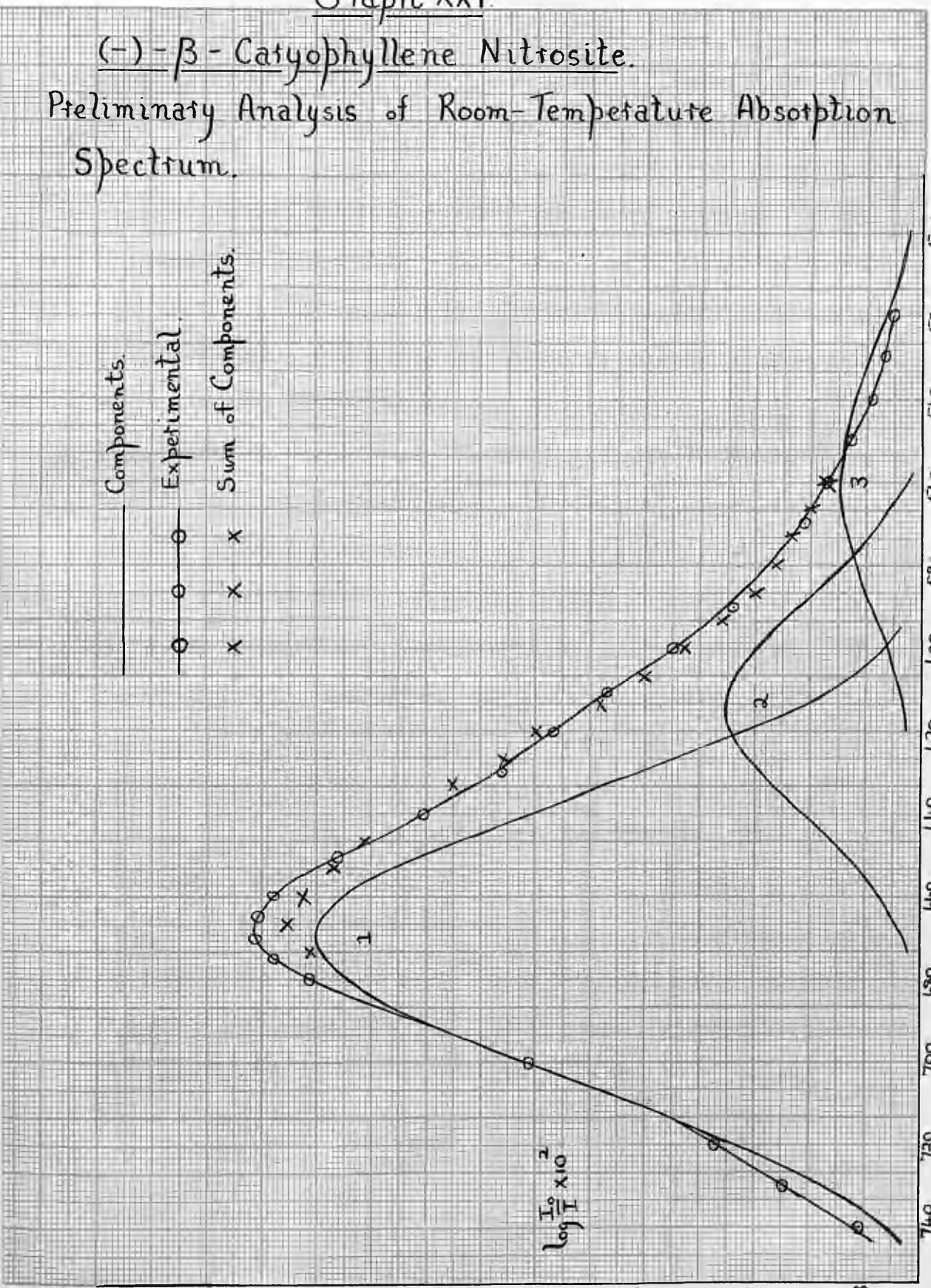
(c) Second small component:-

| λ(A) | $\log I_o/I \times 10^2$ |
|---|---|
| 5500, 5700 | 4.2 |
| 5400, 5800 | 3.6 |
| 5300, 5900 | 2.9 |
| 5200, 6000 | 2.0 |
| 5100, 6100 | 1.3 |
| 5000, 6200 | 0.8 |

Graph XXI

(−) - β - Caryophyllene Nitrosite.

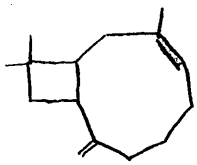
Preliminary Analysis of Room-Temperature Absorption Spectrum.



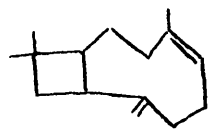
imposed by a large temperature gradient across the outer windows of the Dewar, would contribute a definite amount to the optical rotation. The presence of this gradient is unavoidable if the windows are to be kept free from moisture.

The work of Ingersoll, Slack, O'Connor, Gilmore and Knopf on low-temperature polarimetry has been restricted to measurements on the α-form of nickel sulphate hexahydrate, which owes its activity not to molecular but to crystal dissymmetry. The use of an orientated crystal immersed in the refrigerant (107) eliminated the difficulty outlined in (1) above. Measurements were taken in the ultra-violet (108), the visible (107) and infra-red (109) regions of the spectrum. The methods of measurement were not new, use being made of photographic photometry (108) and differential bolometry (109, 110). It is interesting to note that the rotatory power of a crystal of nickel sulphate increased by 37% at 1.15u where the curve of rotatory dispersion is anomalous (109). The close correspondence between rotation and absorption processes and the enhancement of the latter at low temperatures does not make this result surprising.

The recent establishment of the structure of β-carophyllene by degradative (111, 112, 113, 114) and X-ray diffraction methods (115) as a fused four and nine-membered ring system (below) gives a new significance to the work described in this section.



Barton



Dawson

β-Caryophyllene

The optical constants of β-caryophyllene nitrosite determined by the methods described in the preceding pages, viz.,

$$[\alpha]_{625} = +1794^{\circ} \quad ; \quad [\alpha]_{735} = -2009^{\circ}$$

$$\varepsilon max. = 22.25 \qquad g_o = 0.12$$

make this compound eminently suitable for asymmetric photolysis. This was recognised by Mitchell in 1928. The experimental realisation of this decomposition was not possible however since (a) the complete data for the active form could not be determined so that the amount of induced rotation could not be predicted by Kuhn's equation, and (b) neither the enantiomorph not the inactive compound occurred naturally. It is now

conceivable however, that with the structure established, a synthesis of the dl nitrosite will be achieved and a successful asymmetric photolysis carried out.

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